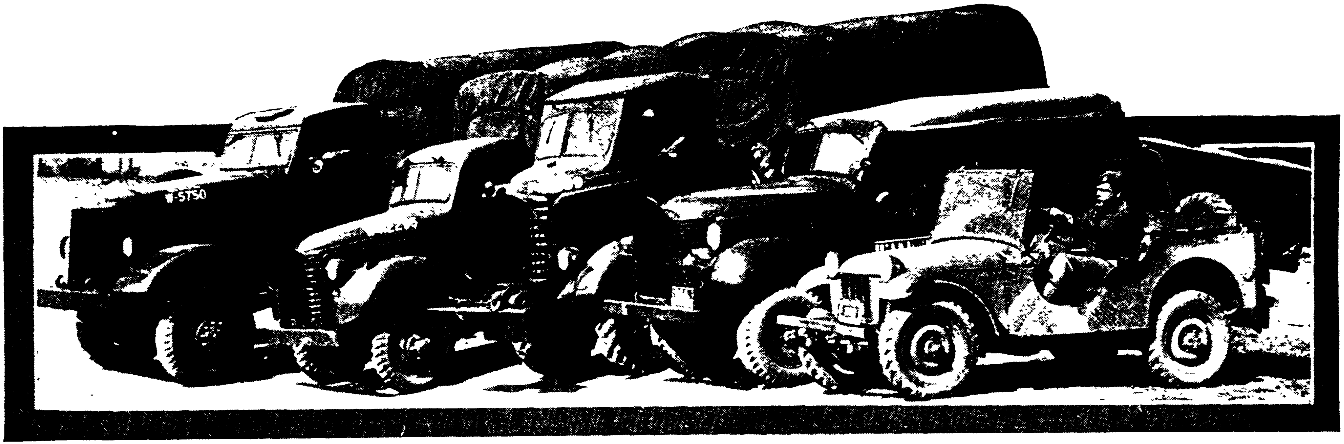

Typical military trucks — Left to right: 6-ton six-wheel truck used to transport a 3-in. anti-aircraft gun; a $2\frac{1}{2}$-ton six-wheel truck used to haul a 75-mm light field artillery piece; a $2\frac{1}{2}$-ton cab-over-engine close-coupled six-wheel truck for transporting light field-artillery guns; a $\frac{1}{2}$-ton four-wheel reconnaissance car; and a $\frac{1}{4}$-ton four-wheel "midget" truck. (*Wide World Photos, Inc.*)

FRASER AND JONES'

MOTOR VEHICLES

AND THEIR ENGINES

FIFTH EDITION

By NORMAN G. SHIDLE
Executive Editor, S.A.E. *Journal*

and

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Technical Editor, S.A.E. *Journal*

WITH THE ASSISTANCE OF

TENCH FRANCIS
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PREFACE

This book is designed to give a clear knowledge of the theory of operation and maintenance of modern automobiles to students approaching the subject for the first time. Technicalities have been reduced to a minimum and fundamentals are stressed in the simplest possible manner.

Aimed particularly at students who subsequently or currently are interested in learning to do practical repair work on automobiles, the principles explained in this volume are drawn exclusively from current American practice and emphasis throughout is laid on designs and constructions in current use. Special attention is given also to relatively new design features which give promise of continued use in the vehicles in which they have recently been adopted or of expanded use throughout the industry.

To avoid confusing the mind of the student, the authors touch only briefly such constructions as are no longer current and such designs as seem clearly on their way out of current practice. Thus the student, when he comes to practical contact with motor vehicles and their parts, will not have his mind cluttered with details about types of units which rarely if ever are met in practice.

Similar advantages of simplification are achieved by confining the descriptive material to examples drawn from the passenger-car field. The principles so developed are applicable to an overwhelming proportion of motor trucks actually in use; *all* of the data regarding engines, tune-up, etc., are directly applicable to trucks as well as passenger cars.

U. S. Army policy of limiting motor truck procurement to models in commercial production makes all the material in this book of practical value in courses looking toward development of men later to be concerned with military transport vehicles. Particularly is this true because nearly 60% of the motor trucks in the U. S. Army program are rated at 1½ tons or less.

To facilitate application of the material to military transport courses, a final chapter describes the modifications made in the design of commercial vehicles to adapt them to military uses — and outlines the special features of military motor vehicles of all ca-

pacities. For the very specific and up-to-date material in this chapter, the authors are indebted particularly to the Chevrolet Motor Division, General Motors Corp., the Fargo Division, Chrysler Corp., the Diamond T Motor Car Co., the Timken-Detroit Axle Co., and to Lt. Col. M. V. Brunson, Quartermaster Corps, U. S. Army.

Since the moving parts of a motor vehicle will not run indefinitely without repairs and adjustments, a section at the end of most chapters is devoted to description of the mechanical troubles most likely to occur; to explanation of the reasons for their occurrence; and to a brief outline of how they are commonly remedied. Thus the student is led directly from construction and theory toward such later contact — formal or informal — as he may have with the use and maintenance of actual motor vehicles.

No attempt is made to instruct the student in detailed repair processes. Before actually proceeding to the making of adjustments and repairs, he would be expected to refer to factory service manuals for the specific make of car to be worked on or to more detailed instruction in repair techniques. Design changes today are too steady and too detailed to make practical the inclusion of such material in textbook form. In a separate chapter, however, the authors do provide the student with methods of obtaining facts about detailed repair methods and indicate certain approaches to the use of that material which should help him more readily to make it his own.

To William H. Hubner, director, Refinery Technology Division, Ethyl Gasoline Corp., the authors express particular appreciation for his preparation of the material which appears as Chapter XXVII ("Motor Fuels") and to J. Howard Pile, editorial director, Chek-Chart Corp., for extensive assistance in preparation of Chapter XXVI ("Chassis Lubrication").

May 1, 1941

Norman G. Shidle.

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To AC Spark Plug Division, General Motors Corp., for Figs. 52 and 70; to Bendix Products, Division Bendix Aviation Corp., for Figs. 67, 186, 187 and 188; to Borg & Beck, Division Borg-Warner Corp., for Figs. 133 and 136; to Buick Motor Division, General Motors Corp., for Figs. 2, 46, 73, 74, 131, 134, 135, 138, 167, 171, 180 and 182; to Cadillac Motor Car Division, General Motors Corp., for Figs. 13, 127, 147; to Carter Carburetor Corp., for Figs. 56, 57, 58, 59, 60, 61, 62, 63, 64, and 65; to Chek-Chart Corp., for Fig. 190; to Chevrolet Motor Division, General Motors Corp., for Figs. 150 and 193; to Chrysler Corp., for Fig. 154; to Delco-Remy Division, General Motors Corp., for Figs. 120, 121 and 122; to Dodge Bros. Corp., Division of Chrysler Corp., for Figs. 192, 194 and 197; to Electric Auto-Lite Co., for Fig. 123; to Field Artillery Manual for Figs. 8, 14, 43, 141, 142, 143, 144, 145 and 181; to Gemmer Manufacturing Co. for Figs. 177 and 178; to Holley Carburetor Co., for Fig. 66; to Hudson Motor Car Co., for Figs. 139 and 140; to Lincoln Motor Division, Ford Motor Co., for Fig. 164; to Long Manufacturing Division, Borg-Warner Corp., for Fig. 137; to MoToR Factory Manual for Figs. 52, 120, 121, 122, 137, 149, 162, 177 and 178; to "News and Views," General Motors Corp., for Figs. 165 and 185; to Packard Motor Car Co., for Figs. 47, 156 and 166; to Pontiac Motor Division, General Motors Corp., for Figs. 42, 44, 45, 51, 116, 148, 163, 168, 174, 175, 183 and 189; to the SAE Journal (Society of Automotive Engineers), for Figs. 146, 147, 151, 152, 153 and 173; to Spicer Manufacturing Corp., for Figs. 15 and 155; to Studebaker Corp., for Figs. 149, 169 and 179; to Timken-Detroit Axle Co., for Figs. 198 and 199; to United Motors Service, Inc., for Figs. 110, 113, 114 and 115; to White Motor Co., for Fig. 200; and to Willys-Overland Motors, Inc., for Fig. 191.

CONTENTS

MOTOR VEHICLES
AND THEIR ENGINES

CHAPTER I

HISTORY OF THE AUTOMOBILE

The dawn of automobile history was back in 1770 when a Frenchman named Nicholas Cugnot built what is generally agreed to have been the first road vehicle propelled by its own power.

Development of the present-day automobile dates from about 1880 when German and French efforts to develop an internal-combustion engine began to bear fruit. Gottlieb Daimler patented an internal-combustion engine in Germany in 1885–1886 and a year later had it running in a vehicle. Benz in Germany built a tricycle propelled by an internal-combustion engine in 1885.

Between 1890 and 1895, European development continued and American designers became active. Before 1895, both Charles E. Duryea and Elwood J. Haynes had experimental automobiles running in this country — and in that year Panhard and Levassor in France evolved a car which, with minor exceptions, incorporated the chief features of the automobile as we know it today. Nearly fifty years ago, this early Panhard had the engine placed in the front of a chassis, hooked up to a sliding-gear transmission, and incorporated brake pedals, clutch and accelerator.

It was 1900 before design improvements awakened the public to the fact that this new form of transportation was really practical for use. In the next six years, production and sale of these vehicles became a business.

Many of the great names around which the world's largest manufacturing industry was to be built in America had already begun to appear before 1906. Packard, Oldsmobile, Overland, Ford, Cadillac, Buick, White, Autocar — all these names were on motor vehicles before 1905, as were scores of others like Pierce-Arrow, Locomobile, Maxwell, Franklin and Peerless which, in their time, were important in the technical as well as the commercial development of the motor vehicle. Even then were being planted the design ideas which suc-

ceeding generations of engineers have tested, refined, improved or discarded as changing demands brought new opportunities for motor vehicle use.

Following this era, when the designer's chief objective was to make his vehicle run, came the period in which development of mass production methods to permit lower prices played a dominant part. In 1908 Ford started off his Model T with an initial run of 20,000 vehicles, an output unheard of at that time. Ever since, the correlation of design with production efficiency has influenced the trend of modern vehicle construction and made possible the use of automobiles by Americans in all income groups.

The early 1920's saw the beginning of a period of gradual evolution and refinement in automobile design. By that time it was clear that the spark-ignition gasoline engine was to be the powerplant of the modern motor vehicle. Steam and electric rivals were clearly on their way out. The sliding-gear transmission had established itself as predominant. Water-cooled engines were almost universal. The poppet valve was used in almost every engine design. Engines were all positioned in the front of the chassis.

Since the early '20s, major improvements have been made in every car feature, but basic changes have occurred in only a few instances. The dominant idea in the designer's mind has been to develop a vehicle which will function at all times under all conditions and which will be increasingly comfortable to ride in and easy to operate. The life of tires has been increased many times; independent front wheel suspension has almost entirely replaced the rigid front axle on American cars; four-wheel brakes are universal and most of them are hydraulic; engine compression ratios have gone steadily upward, producing more power in an engine of given size; availability of new materials and new types of old materials have influenced the design of scores of individual vehicle parts — hundreds of other changes have been made. Through all of the changes in recent years, however, runs the theme of evolution rather than revolution; refinement rather than reconstruction.

Whatever tomorrow may bring, its innovations seem certain to have some roots in the past — some tie to current practice. That has been true of independent wheel suspension, fluid flywheels, free-wheeling, overdrives, four-wheel brakes and a majority of other of the newer features of today's car. At one time or another the principle had been tried previously somewhere, long before the refined unit found its place as part of commercial design. So with the most-discussed future possibilities. Cars had engines in the rear before

they had them in the front. The diesel engine was invented only a few years after the spark-ignition engine. Automatic transmissions will be new in design — not in principle.

The whole history of automobile design emphasizes a knowledge of basic principles as the unifying link between the past, present and future.

Design trends of recent years have provided the owner with cars that are easier to drive, more reliable and more comfortable. One result has been to turn more and more owners to professional repair men in case of even minor mechanical difficulties. The car owner of yesteryear of necessity knew something about repairing his vehicle. A large proportion of the more than 40,000,000 drivers in the United States today know very little; about 18% are women. The greatly increased standards of comfort in operation, moreover, make them far more exacting than the owner of former years. The driver who once was happy to have his car run, now insists that acceleration be always up to par. The old timer was glad to have an open body instead of a box to sit on. Today's driver objects to squeaks or rattles in the closed body which protects him from elements and accidents.

The modern trends have created new opportunities for the professional repair man and new requirements for the owner who still wishes to do his own repairs. Too, they have brought need for fresh knowledge for everyone who may be called upon to understand the workings of a motor vehicle as an occasional or subsidiary part of his business, military or social life.

CHAPTER II

THE MODERN AUTOMOBILE

The whole structure of the modern automobile — body, chassis, engine . . . everything — must be considered as a single unit. The construction and performance of every part are integrally related to the structure and performance of every other part to a degree not thought of when automobiles first were built.

The early cars consisted of a chassis in which was incorporated an engine to furnish power for movement. A place for the driver was provided as a necessary after-thought. Sometimes he had little more than a box to sit on. Early improvements designed to make riding not merely possible, but pleasant as well, followed carriage-building patterns. Chassis were designed. Then designers schooled in the carriage-building tradition made bodies which were fitted to the chassis as best they might be.

Gradually conditions changed. Chassis and engine reliability came to be normal expectancy and owner demands for greater riding comfort accelerated. In recent years, the old order has almost been reversed. Chassis construction has been forced to shape itself to pre-designed bodies in more than a few instances.

Out of this slowly shifting emphasis has grown the modern concept of the whole automobile as a single unit in which simultaneous or closely-coordinated conception of chassis and body is axiomatic. There can be little doubt that, as time goes on, engineering organization as well as engineering thinking will accelerate its adaptation to the most efficient carrying out of this relatively new practice.

Already several designs eliminating the conventional frame and using the body itself as a stressed unit stand as symbols of the general idea of the modern car as an integrated unit. The modern automobile is best understood, therefore, when it is considered as a coordinated group of parts, each designed and modified in relation to every other part in the group in such a way as best to perform the function of safe, comfortable, individual transportation for which the completed vehicle is designed.

This typical modern vehicle begins to perform its function when the driver turns on an ignition switch which releases electrical current from a battery. He then pushes or pulls a button which actuates

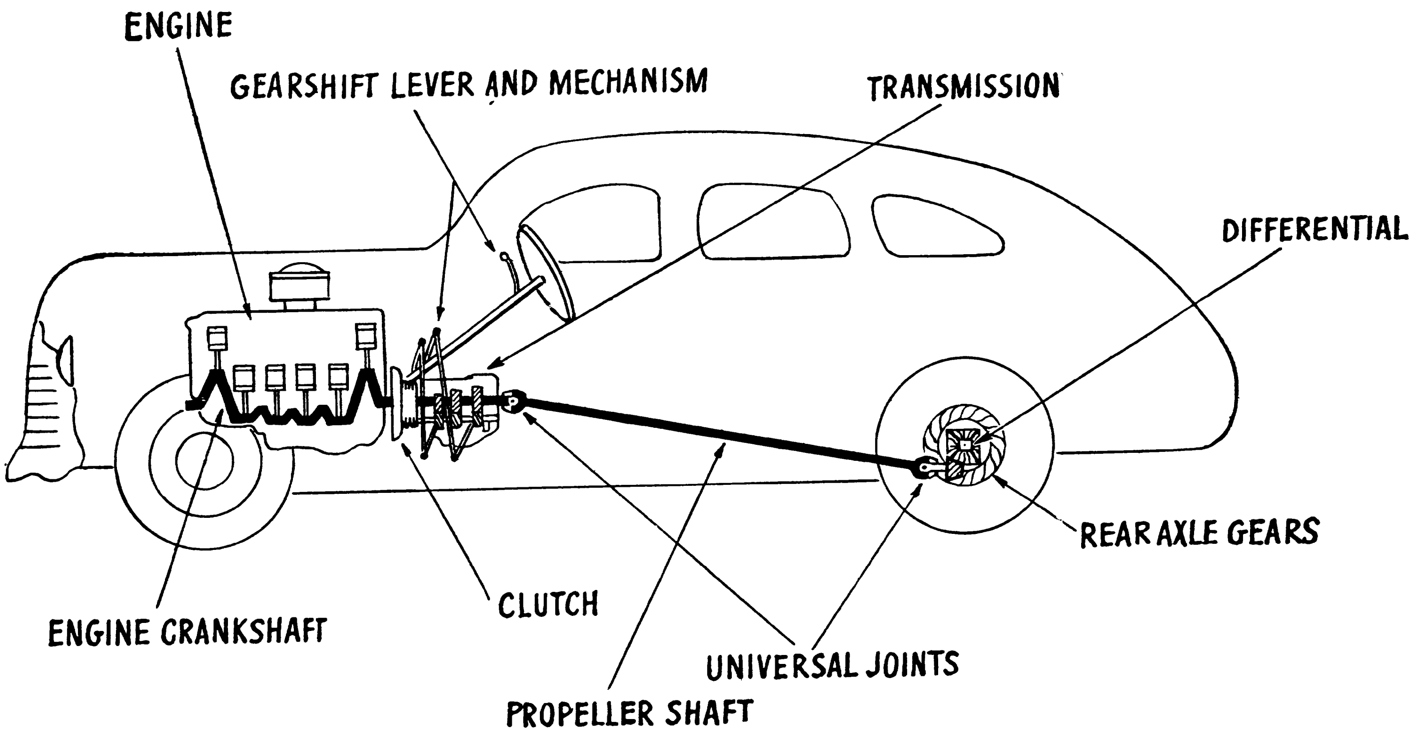


Fig. 1 — Flow of power from engine to rear wheels in a modern passenger car

an electrical starting motor which turns a flywheel connected to the engine crankshaft.

Immediately, the driver steps on a pedal which controls the rate at which gasoline flows into a chamber called a carburetor. There the gasoline is mixed with air to form a mixture which will burn. This mixture is sucked into the engine cylinders, an electrical spark sets fire to it, the resulting explosions turn the crankshaft — and the engine is running (Fig. 1). As the explosive process is repeated over and over again, the crankshaft is turned continuously.

Through a mechanism called a clutch, this crankshaft is then connected at the will of the driver to a set of gears (a transmission) which starts the transmission of the power from the engine to its ultimate destination — the rear wheels. By means of a gearshift lever, the gears of the transmission can be shifted to suit driving conditions.

As the transmission gears change, they set in motion a propeller shaft to which they are connected by a universal joint. The rear end of the propeller shaft connects to another set of gears (bevel gears) through which the power from the propeller shaft is enabled to turn the corner into the rear axles which extend at right angles and thence to the wheels. (A third set of gears, called a differential, is arranged in the rear axle to permit one rear wheel to turn faster than the other when necessary, as when turning a corner.)

The wheels, being connected directly to the rear axles, turn as the rear axle shafts turn — and the car is in motion.

While there is a multitude of detailed variations in the means by which this whole process is accomplished, the foregoing describes briefly how an automobile works.

As this modern car rolls along the road, it is directed by a steering gear which controls the direction in which the front wheels are pointed. The conflicting movements imparted to the rider by the forward movement of the car and the unevenness of the road surface are partially controlled by springs, front and rear; by shock absorbers which help to damp out sudden recoils in these springs; by padding and springs in the car seats themselves; by chassis cross members which decrease sidesway; and by the distribution of chassis and body weight as between front and rear wheels.

The body in which the driver of this modern car rides is constructed of steel and probably is either a two-door sedan, a four-door sedan or a coupe. In a small minority of cases it is a convertible coupe, a convertible phaeton, a roadster or a phaeton.

A wide variety of sales nomenclature has made difficult uni-

versally exact definitions of each of these body types, while the special names applied to variations of each type are legion. Current usage, however, renders reasonably accurate the following definitions of these most common body types:

Two-door Sedan. — An enclosed two-door type of body with permanent back-panels and top. A full-width seat in the rear accommodates three passengers. A full-width front seat with divided back accommodates the driver and one or two additional passengers. Folding down the front-seat backs allows unobstructed entrance or exit to rear-seat passengers.

Four-door Sedan. — An enclosed four-door type of body with permanent back-panels and top. A full-width cross seat in front and rear. Passenger capacity from five to eight according to wheelbase or body design. May or may not be provided with windows in the rear-quarter.

Coupe. — An enclosed single compartment body. Passenger capacity varies with arrangement of seats or length of wheelbase. Two doors are provided. Back-panels and top are permanent. Larger types may be provided with quarter windows.

Roadster. — An open-type body having one cross seat. A compartment in the rear deck accommodates luggage and/or an extra seat for two persons. Has two doors.

Phaeton. — An open-type body with two cross seats, usually accommodating five passengers. Has four doors.

CHAPTER III

BEARINGS, GEARS, UNIVERSAL JOINTS AND SLIP JOINTS

Certain parts are common to many of the various units which comprise the automobile chassis and engine. Important among these are bearings, gears, universal joints, and slip joints. Knowledge of the purpose, construction and operation of these parts is necessary to clear understanding of the various chassis and engine units described in later chapters.

Bearings. — Bearings are used in all types of machinery, engines, and mechanisms for supporting and controlling the motion of rotating, sliding, or reciprocating parts. Rotating parts that are supported and controlled by bearings are usually called shafts, spindles, or axles. Bearings are designed to serve their purpose with a minimum of friction, power loss, and generation of heat, and are aided in this requirement by suitable lubrication. Bearings that support the rotating shaft in a fixed position against loads acting perpendicular to the axis of the shaft only are called "radial bearings"; those that also are called upon to resist loads parallel to the axis of the shaft or bearing are called "thrust bearings"; and those that limit the motion of the shaft or moving part to a straight line are called "guide" or "slipper bearings."

Bearings used in motor vehicles are classified as to design as "plain" bearings, "roller" bearings, and "ball" bearings. The last two types are commonly termed "antifriction" bearings because of their low frictional loss.

Plain Bearings. — Plain bearings encircle the shaft directly, and the bearing and shaft usually are made of dissimilar materials separated from each other by a film of lubricant. The part of the shaft which rotates in the bearing is called the "journal." Plain bearings usually have a lining of low-friction material which supports the shaft through the oil film. Plain bearings are used almost universally throughout the engines of motor vehicles, even though their frictional losses are higher than the antifriction type, because they are necessary to obtain sufficient bearing surface to withstand the heavy radial thrust resulting from the power impulses in the cylinders. The usual construction is to finish and polish the journal of

the shaft or pin to a mirror-like surface to bear against the lining through the oil film. These bearings are generally of the split type, and the lining material sometimes is poured or " spun " directly on the bearing seat. It usually is furnished as a separate replaceable unit, however, as shown in Fig. 2. Separate linings usually are strengthened by a steel or bronze backing. These linings contain suitable holes and grooves to admit and distribute the lubricating oil, as shown in the illustration. The lining material used in passenger-car engine main bearings and connecting-rod bearings is usu-

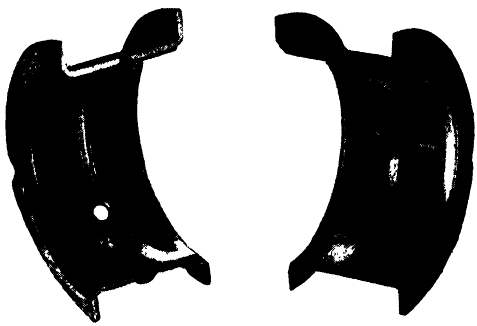


Fig. 2 — Typical steel-backed main bearing of passenger-car engine

ally babbitt backed by steel or bronze. Because of their higher melting points and greater hardness, copper-lead and cadmium-silver linings are sometimes used, especially in engines where speeds, temperatures, and loads are unusually high. Plain bearings in the form of bronze, brass, or " oilless " bushings, also are found on parts of motor vehicles where a loss of energy due to friction is unimportant, as on gear pedals, spring bolts, and so on.

Roller Bearings and Ball Bearings. — These types are known as antifriction bearings because their frictional losses are many times less than equivalent plain bearings. Both substitute rolling for sliding friction. Roller bearings theoretically provide line contact and ball bearings point contact. Actually the rollers and balls flatten somewhat under load causing some sliding in operation. These bearings need occasional lubrication to facilitate this sliding and to protect their highly polished surfaces. Roller and ball bearings are used throughout the power-transmission systems of passenger cars. Roller bearings are used when the load is heavy or the end thrust is great, and ball bearings are usually applied when the load on the bearing is uniform and not heavy, although special types of ball bearings are designed to take end thrust and heavy loads.

Fig. 3 shows typical commercial constructions of ball and roller bearings. Ball bearings are classified as radial, angular, or thrust. The ball bearing shown at *A* is a cup-and-cone or " angular " design. This bearing has an angular contact and is capable of taking radial and light thrust loads. The balls are of hardened steel. Such bearings are adjustable to a slight degree as lost motion may be eliminated by forcing the cup or cone into more intimate contact with the balls. The ball bearing shown at *B* is of the annular or " radial " type and is adapted only for radial loads and for very light end thrust; it is not adjustable. Since there is only theoretical point contact in ball bearings, friction is low and only light oil need be supplied at infrequent intervals for lubrication. In addition to the types shown, two rows of balls may be provided. Cages are supplied in some types to keep the balls properly spaced and aligned. Thrust ball bearings are used to take thrust only; in construction, one or more rows of balls are carried in cages between vertical thrust races.

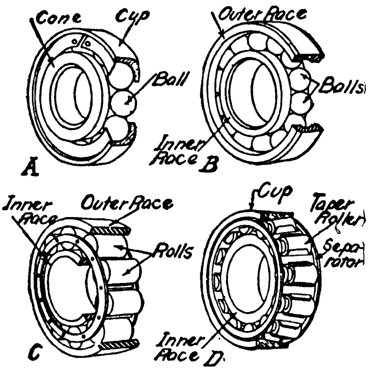


Fig. 3 — Typical ball and roller bearings

The roller bearing shown at *C* is provided with straight rollers and can take only radial loads. That shown at *D* employs conical race members and correspondingly tapered rollers. Bearings of this type will carry not only radial loads but also will resist end thrusts. Tapered roller bearings are adjustable for wear by moving one of the race members into closer contact with the rollers. Roller bearings, having a theoretical line contact, are stronger than ball bearings of the same size, but they absorb more power because of the increased surfaces in contact. Therefore, heavier oil and more lubrication are necessary than with ball bearings. In tapered roller bearings the conical surfaces of rolls and races taper to meet at a common apex, so that the speeds of all rolling surfaces are related correctly.

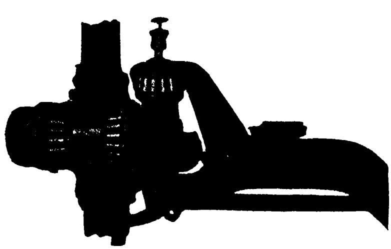


Fig. 4 — Tapered roller bearing installation

Fig. 4 shows a typical installation of tapered roller bearings on the front wheels and knuckles of an automobile, arranged to carry both the radial and thrust loads. These bearings are usually used in pairs, each bearing resisting the end thrust in one direction.

Roller bearings are either solid or constructed as shown in Fig. 5. These rollers are constructed by rolling strips of steel into spirals or helixes and are arranged in the bearing so that the right and left helixes alternate. This construction gives increased flexibility, reducing the transmitted strain resulting from sudden shock. The rollers are aligned and spaced by central pins, permitting use of a large number of rollers. In addition, the arrangement of the helixes is such as to keep the lubricant in continuous circulation over the entire bearing surface.

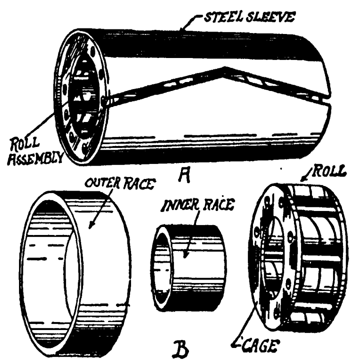


Fig. 5 — Flexible- or spiral-roller bearings

The cages or separators used to space the balls and rollers in antifriction bearings are constructed so as to present the minimum amount of surface to the moving parts. These cages are usually made as light as possible and of relatively soft material, such as brass. One type of roller bearing uses barrel-shaped rollers which approximate the contact of ball bearings when under light load but, as the load increases, the bearing area grows larger. Accurate fittings and close adjustment are obtained with solid rollers. Races, cones, and cups usually are of case-hardened or completely hardened steel. Bearing surfaces are ground, lapped, and honed to a precision mirror finish.

Gears. — Gears are used to transmit power from one shaft to another at a predetermined positive speed ratio. A mechanical advantage may be obtained by the use of gears, permitting heavy loads to be lifted with less power than without them, but with a corresponding reduction in speed. Conversely, speeds may be multiplied by the use of gears, with a corresponding reduction in the torque or twist transmitted. Gears also are used to change the direction of rotation.

Fig. 6 shows how a mechanical advantage is obtained by use of gears. At A a weight W is shown supported by a rope wound about a roller R. When the crank C is turned, the rope is wound upon the roller, lifting the weight. The force required to lift the weight will

depend upon the length of the crank arm *C* and the diameter of the roller *R*. At *B* in Fig. 6 is shown the same weight supported by the rope wound on the roller *R* of exactly the same size but made fast to the large gear wheel *G*. Meshing with *G* is a smaller gear or pinion *P*, to which is attached a crank *C* of the same length as before. When the crank is turned, pinion *P* revolves, causing gear *G* to revolve also and lift the weight *W* by winding up the rope on roller *R*. The force required to lift the weight *W* in this case will be considerably less than before because of the gear reduction between crank *C* and roller *R*. The speed at which the weight *W* is

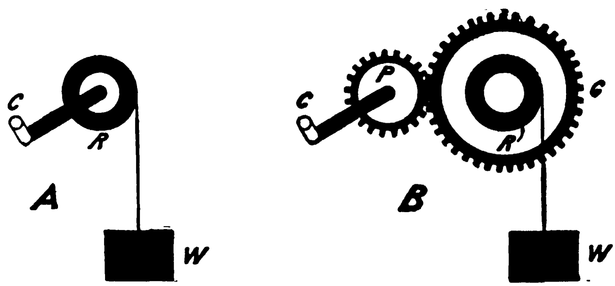


Fig. 6 — Mechanical advantage of gears

lifted, however, will be lower than before if the crank *C* is rotated at the same speed in both instances, also because of the gear reduction. In both cases the total work done in lifting the weight through a certain distance is the same. In the first case, one revolution of the crank winds one turn of rope upon the roller, lifting the weight a corresponding amount. In the second case, one revolution of the crank does not turn the gear *G* one revolution because the pinion *P* can turn *G* only as many teeth as are on the total circumference of *P*. If the gear has twice as many teeth as the pinion, two turns of the crank will be required to revolve the roller once. Hence, two turns of the crank at *B* would lift the weight *W* only as far as one turn did at *A*, but only half as much force (disregarding friction) would be required. It can thus be seen that the force necessary to do a given amount of work can be reduced by the use of gears, but the force will need to be applied for a longer time. The amount of reduction depends upon the number of teeth on the two gears in mesh.

By the use of gears in the transmission, an automobile engine is able to pull a heavy load up a steep grade. Their use also explains why the speed of the rear wheels, and consequently that of the car, decreases while the engine continues to run as fast or even faster than in high gear when the gears are not in use.

When two or more gears are meshed, one driving the other, they will rotate as shown in Fig. 7. At *A*, two spur gears are shown in mesh. If *P* turns as indicated, it will drive *G* in the opposite direction. At *B* are shown an internal gear and pinion in mesh. If *P* turns as indicated, it will drive *G* in the same direction. The rotations of combinations of more than two gears, as shown at *C*, can

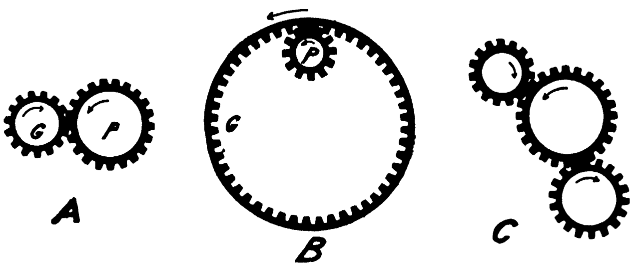


Fig. 7 — Rotation of gears

be traced out by applying the same fundamentals. It will be noted that the top and bottom gear in the combination shown at *C* have been made to rotate in the same direction by interposing a third gear in the center.

The expression " gear ratio " or " gear reduction " is defined as the relation between the number of teeth on one gear as compared with the number on the gear which drives it. For example, if one gear having 42 teeth is driven by a gear having 12 teeth, the gear ratio is 42 to 12 or $3\frac{1}{2}$: 1, the number of revolutions made by the driving (or 12-tooth) gear for every revolution made by the iarger driven gear.

Gears are classified in several ways:

1. According to the arrangement of the teeth along the width of the gear:
   a. Straight (spur gears)
   b. Spiral (helical gears)
   c. Double spiral (herringbone gears)
2. According to the relative position of the two shafts connected by the gears:
   a. Parallel shafts (plain or internal gears)
   b. Shafts at any angle in the same plane (bevel gears)
   c. Shafts at any angle not in the same plane (worm gears, hypoid gears)

Various combinations of these two classifications are used in the types of gears employed in motor vehicles. Thus, a gear with its teeth arranged along its width in any of the foregoing three ways

may be designed to connect shafts located in any one of the three relative positions indicated in the classification.

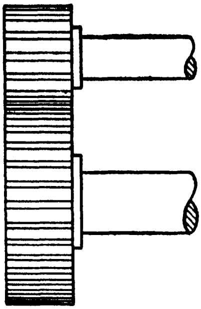


Fig. 8 — Spur gears

The arrangement of teeth in spur gears is straight across the face of the gear as shown in Fig. 8 which illustrates the " plain " type of spur gear with the two shafts parallel. Spur gears have advantages of strength and simplicity; they generate no end thrust; and can be mounted easily for sliding mesh. Since it is difficult to mesh fully more than one pair of teeth at a time, spur-gear teeth must be strong enough to withstand the bending stresses produced by transferring the load from one pair of teeth to the next. They are noisier in operation than helical or spiral gears.

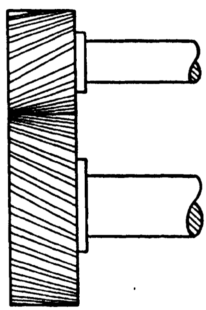


Fig. 9 — Helical gears

On the helical or spiral gears, on the other hand, the gear teeth extend " helically " across the face of the gears as shown in Fig. 9, illustrating a " plain " helical gear. The form of the curve, a " helix," is made by a line wrapped around a cylinder, such as is traced by an ordinary screw thread. With this design it is easier to distribute the load among two or more teeth at the same time. For this reason helical gears can be made lighter and can run at high speeds without setting up troublesome vibration. Because of the angle of their teeth, helical gears set up end thrust; therefore, provision must be made in the bearings of the shafts carrying these gears for this end thrust. When mounted properly, they can be used in sliding mesh. Because of their silence and smoothness in operation, helical gears are used extensively in passenger-car transmissions and overdrives.

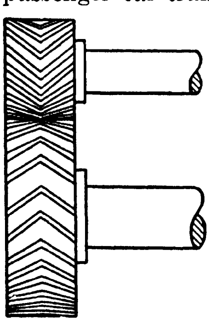


Fig. 10 — Herring-bone gears

The teeth of the herringbone gears (Fig. 10) form the familiar herringbone pattern across the face of the gear. Actually they are cut in dual helical form. It is obvious that this construction neutralizes end thrust, and cannot be slid out of mesh.

Bevel gears are usually employed so that power can be transmitted from one shaft to another shaft at an angle to it but in the same plane. This angle is usually 90 deg or a right angle as shown in Fig. 11. Bevel gears are usually of the helical type shown or of the spur type. The

outlines of bevel gear teeth are generated in the form of a pair of cones whose vertexes coincide at the point of intersection of their axes. The small gear is called the pinion, and the large gear, the ring gear. There is, of course, a gear reduction from the small to the large gear. When their teeth are straight they are called spur-bevel gears; when they are helical or spiral, they are known as helical-bevel gears. Helical-bevel gears are quieter and smoother in operation than the spur-bevel type. Helical-bevel gears also permit a greater speed reduction than the spur type.

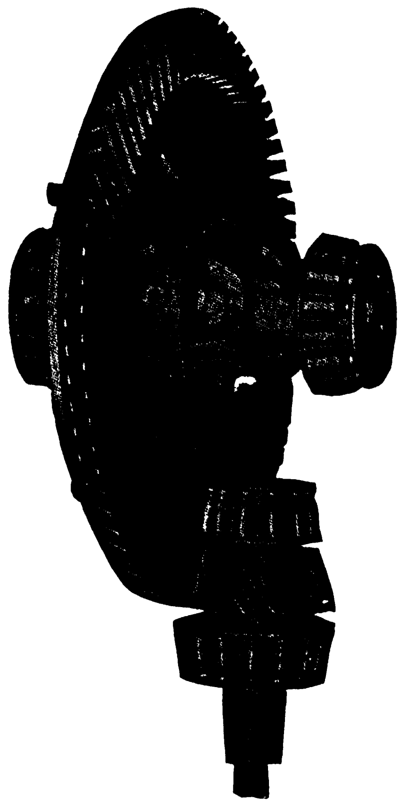


Fig. 11 — Helical-bevel gears

Worm gears are another method of obtaining angular transmission of power (Fig. 12). They are classified as a special type of helical gear, the shafts of which make an angle of 90 deg with each other but are not in the same plane. At the same time they permit large gear reductions. As shown by the illustration, the worm is provided with threads that take the place of teeth on bevel gears. The worm is usually cylindrical as shown, but may be shaped like an hour glass. Because of their design there is considerable sliding friction between the teeth when they are in operation. The heat generated by this friction is minimized by employing dissimilar metals for the worm and wheel, usually bronze for the worm and steel for the wheel, and by the use of suitable lubricants. In aligning the worm gear and wheel or ring gear, allowance must be made for the expansion of these gears caused by the heat of friction. Worm gears are strong and operate quietly. A different size worm may be used with the same wheel when it is desired to change the gear ratio. Worm gears are sometimes used in the final drives of trucks and have been used in passenger cars.

The large gear at *B* in Fig. 7 is an internal gear with the teeth cut on the inside of the ring of the gear. The teeth may be either

of the spur or helical type. Use of the internal gear in a " planetary " gear set will be explained in the discussion of overdrives in Chapter XXI on the transmission. Shafts of commercial internal gears are always parallel.

Fig. 13 shows a set of hypoid gears. These gears are used in the final drive of an overwhelming majority of American passenger cars. As shown, their shafts are at a 90 deg angle, but are not in the

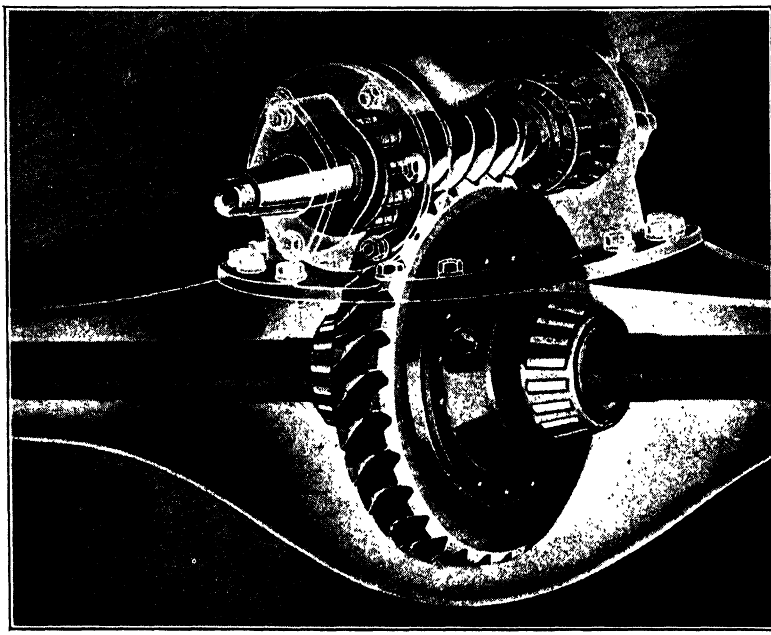


Fig. 12 — Worm gears

same plane. They may be defined as a special type of helical-bevel gear in which the axis of the pinion is perpendicular to the axis of the ring gear but does not intersect with it. This difference in level between the axes of the two gears permits the floors of passenger cars to be lower with the same axle clearance than when spiral-bevel gears are used. The operation of these gears in the final drive of a passenger car is discussed in more detail under "Final Drives," in Chapter XXIII.

Universal Joints. — Universal joints are used to make a flexible connection between two shafts at an angle with each other. They permit the transmission of power not only at an angle, but also while this angle is being varied constantly. In motor vehicles they are used not only to permit power to be transmitted from the horizontal transmission mainshaft to the propeller shaft which is nor-

mally at an angle with the horizontal because the rear axle is usually lower than the transmission mainshaft, but also while the flexing of the springs caused by road irregularities is constantly changing this angle. Without such a flexible device the transmission of power under these conditions would be impossible. Fig. 14 shows a simplified sketch to illustrate the fundamental principle of all universal joints. As shown, the joint consists of two yokes (one attached to the end of each shaft to be joined) and a central or connecting piece.

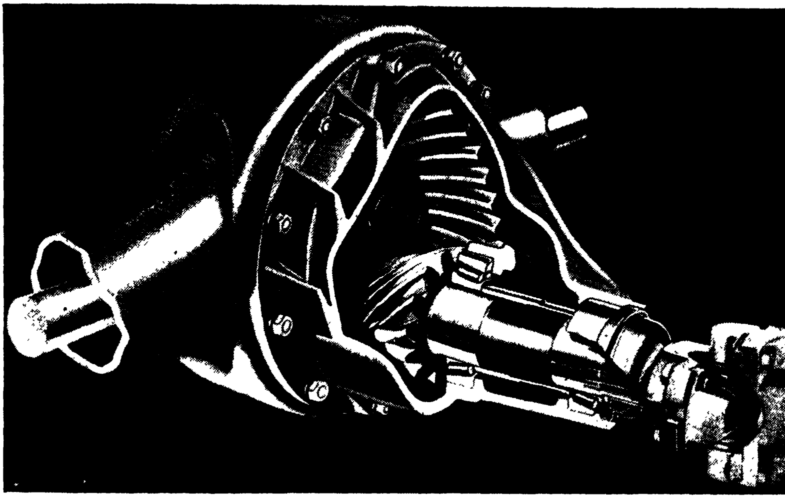


Fig. 13 — Hypoid gears

It can be seen that the shafts in the connecting piece will turn in the bearings of the yokes in accordance with the change in angularity between the shafts. Fig. 15 shows a needle-bearing type of universal joint commonly used in passenger cars. It employs roller bearings of the needle type, and is packed in lubricant and sealed. Passenger-car universal joints have an efficiency ranging from 97 to 99%.

Except for special " constant-velocity " types rarely found in passenger cars, universal joints do not transmit the motion uniformly when the shafts are operating at an angle. Because the pivot pins do not revolve in the same plane, the driven shaft will increase to a maximum and decrease to a minimum twice in each revolution. The degree of the variation is small, however, and may be minimized, when two universal joints are used, by arranging the two joints so that the non-uniform rotation of each joint tends to neutralize that of the other. The arrangement of the universal joints in passenger cars and their relationship to other parts are discussed more fully in Chapter XXII on power transmission.

Slip Joints. — When a shaft transmits power between two points, and the distance between these two points is constantly changing, some means must be provided to compensate for this change in length or the shaft would buckle or break. This condition exists in many passenger cars between the transmission mainshaft and the rear-axle drive, between which two points the propeller shaft transmits power.

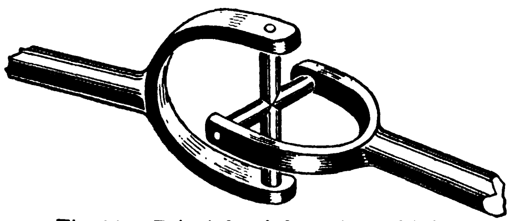


Fig. 14 — Principle of the universal joint

As has just been explained, the propeller shaft usually inclines downward from the transmission mainshaft to the rear axle. Now, when the axle rises as the rear springs are compressed, the propeller shaft is shortened, and lengthened again when the axle returns to its original position. To compensate for this change of length and to permit it to transmit power from the engine to the rear axle at

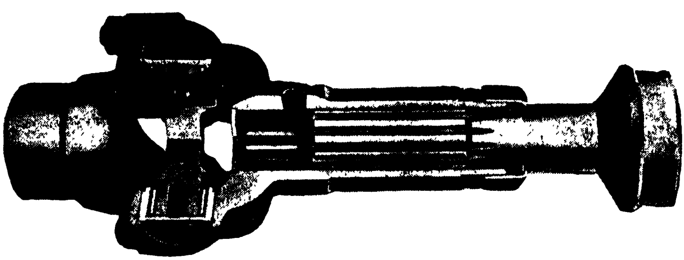


Fig. 15 — Needle-bearing type of universal joint

the same time, a slip joint is incorporated between the propeller shaft and the universal joint connecting the propeller shaft with the transmission mainshaft in designs of passenger cars using the "Hotchkiss drive." In cars provided with a "torque-tube" drive, a slip joint is not necessary. The construction and operation of these two types of drive will be explained in Chapter XXII. As shown in Fig. 15, this joint is comprised of a male splined end of the propeller shaft which is free to slide in corresponding grooves in the female member of the joint which is integral with the universal-joint hub. The splines enable the slip joint to transmit power while it is sliding to compensate for changes of length in the shaft.

CHAPTER IV

THE ENGINE — HOW IT FUNCTIONS

The unit which furnishes the power to propel the modern automobile is a gasoline-burning, spark-ignition, four-stroke-cycle, internal-combustion engine. Like all other types of internal-combustion engines, its ability to furnish this power rests on two basic principles of physics:

1. Combustion or burning is always accompanied by the production of heat; and,
2. When a gas is heated, it expands.

What actually happens in the production of power by this internal-combustion engine may be described as follows:

Gasoline, a liquid fuel, is mixed with air in a carburetor and the mixture is sucked into a cylinder. There it is compressed by the upward movement of a piston within the cylinder and is ignited by an electric spark. When the mixture in the cylinder is burned, the resulting heat causes the gases to expand. Since the natural expansion is inhibited because the gases are confined within the cylinder, pressure is exerted on the cylinder walls and on the piston. The piston, being movable, is pushed downward by the force of these expanding gases to the full length of its stroke.

To transfer into useful work the energy resulting from this expansion, a construction such as shown in Fig. 16 is used.

As is shown, the force exerted on piston *K* is transmitted through the connecting rod *E* to the crankshaft *H* which is made to revolve, turning through one-half of a revolution as the piston moves downward. Attached to the crankshaft is a flywheel, which stores up energy, and its momentum carries the piston through the balance of its motion until it receives another power impulse. In this way the reciprocating motion of the piston is transformed into a rotary motion at the crankshaft. (From that point on the power is transmitted back to the rear wheels as indicated in Chapter II.)

In order that the operation of the engine be continuous, this series of events must be repeated over and over again in regular order. These events that are repeated comprise the " cycle " of the engine.

To understand clearly this series of events, it may well be compared to the operation of an old-style muzzle-loading cannon, which is the simplest form of internal-combustion engine.

The first step necessary to fire the cannon, as illustrated in Fig. 17, is inserting the charge; the corresponding step in the gasoline engine is the admission of the charge. The second step is ramming the projectile and powder; the corresponding step in the gasoline engine is the compression of the charge. The third step is lighting

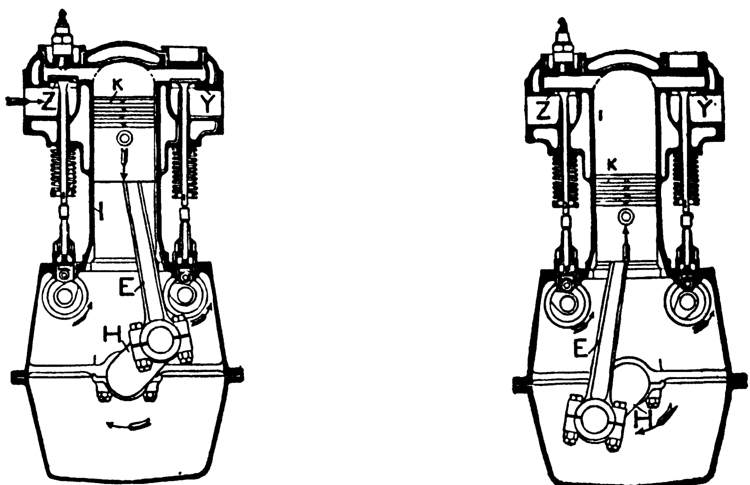


Fig. 16 — Engine operation

the fuse; the corresponding step in the gasoline engine is the ignition of the charge. The fourth step is burning the powder and the fifth step expansion of the gases of combustion due to the heat produced which forces the projectile out of the cannon. The corresponding steps in the gasoline engine are the burning of the charge and the expansion of the gases.

The sixth and last step in operation of the cannon is the escape of the burned gases after the projectile has left the muzzle; the corresponding step in the gasoline engine is the subsequent exhaust of the products of combustion. The cannon is now ready to be fired again and the engine to continue its operation.

The steps comprising the cycle of operation of the gasoline engine, then, may be summarized as follows:

1. Admission of the charge
2. Compression of the charge
3. Ignition of the charge

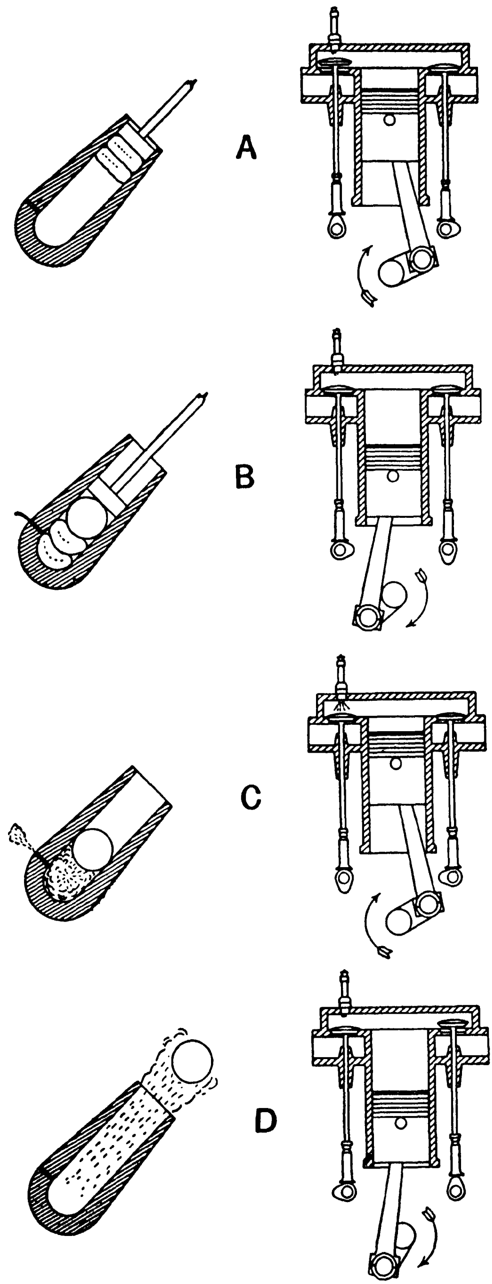


Fig. 17 — Operation of cannon and engine compared

4. Combustion of the charge
5. Expansion of the gases
6. Exhaust of the gases

The number of strokes of the piston required to complete the cycle varies with the type of engine. In the type universally used in modern American passenger cars, the cycle is extended through four strokes of the piston or two revolutions of the crankshaft. The engine is therefore called four-cycle. (Were the cycle completed in two strokes of the piston or one revolution of the crankshaft, as is the case in some engines not at present used in American passenger cars, but emphasized in some diesel-powered trucks and buses, the engine would be called two-cycle.)

In the four-cycle engine, the four strokes are named suction (or intake), compression, power and exhaust in accordance with the operations of the cycle which occur during each particular stroke.

Suction Stroke. — During this stroke (Fig. 17*A*), the piston is moved downward by the crankshaft, which is revolved either by the momentum of the flywheel or by the power generated by the electric starting motor. This movement of the piston increases the size of the combustion space, thereby reducing the pressure in it. Then the higher pressure of the outside atmosphere forces fresh mixture into the combustion space through the open inlet valve.

Compression Stroke. — The compression, ignition, and much of the combustion of the charge take place during the next upward stroke of the piston (Fig. 17*B*). The time elapsed between the mixing of the gasoline and air and its admission to the cylinder (through an inlet valve) is too brief to secure a perfect combustible mixture. What passes into the cylinder consists of air, gasoline, and a more or less perfect mixture of the two. To obtain a more homogeneous mixture, advantage is taken of the heat produced by compression. This makes the gasoline easier burning, while the compression forces it into intimate combination with the air. Even then a perfect mixture may not result, for the air and gasoline vapor, instead of being thoroughly combined, may be in layers. The combustion would then be slow and uneven. When the air and gasoline vapor in the mixture are properly proportioned, this difficulty is seldom encountered. The mixture is ignited while under compression, and combustion is over half completed when the piston is at top dead-center. It will be noted that both inlet and exhaust valves are closed during this stroke.

Power Stroke. — The expansion of the gases due to the heat of

combustion exerts a pressure in the cylinder and on the piston. Under this impulse the piston moves downward. (Fig. 17*C*) Both valves also are closed during much of this stroke.

Exhaust Stroke. — When the exhaust valve is opened, the greater part of the burned gases escape due to their own expansion. The upward movement of the piston pushes the remaining gases out of the open exhaust valve. The space between the cylinder head and the piston, when it is at its topmost point, is called the clearance and will contain what little exhaust gas may remain. This remaining gas will dilute the fresh incoming charge (Fig. 17*D*).

Thus it is seen that, in this type of engine, four strokes of the piston are required to complete the cycle.

This cycle or series of events takes place over and over again. The result is delivery to the rear wheels (through the various units of the power transmission system) of a part of this power generated by the production of heat in the cylinder caused by the burning of fuel. A given amount of fuel produces a certain amount of heat when completely burned.

The total heat value of the fuel cannot be utilized, however, because there are certain losses which always must occur even in the best-designed engines. Moreover, badly worn engines, imperfect carburetion, and faulty ignition will add to these necessary losses and decrease the percentage of energy actually available for useful work.

The percentage of the total heat value of the fuel which actually *is* converted into useful work is the measure of what is called the thermal efficiency of the engine. Under the very best conditions not more than 25 to 30% thermal efficiency can be obtained from gasoline automobile engines.

From 70% to 80% of the total fuel value is lost in heat which is absorbed by the cooling system and in heat which is lost in the exhaust gases — and this loss cannot be reduced materially below this amount. Other losses arising from engine friction will vary considerably with the design, condition and temperature of the engine and the viscosity of the oil used to lubricate it.

Engines of all kinds are rated in horsepower — the measure of the rate at which they can do work. One horsepower represents 33,000 ft-lb of work per min. There are two ways of measuring engine power: (1) The power developed by expansion of the gases in the cylinder can be determined (as by indicator cards), in which case the indicated horsepower is obtained. (2) By means of such measuring instruments as a prony brake or a dynamometer, the

power which the engine actually delivers can be measured — and this is called the brake horsepower.

The brake horsepower of an automobile engine usually will be from 70% to 85% of its indicated horsepower, the difference resulting from the losses accruing from energy being consumed in friction, energy consumed in getting the charges in and out of the cylinders, and other causes in the engine mechanism.

Formulas based on the indicated horsepower with certain standard conditions assumed are often used as a basis for taxation of automobiles. The results given by any such formulas bear no relation to actual horsepower — either indicated or brake — so far as modern automobile engines are concerned.

Engine Varieties. — Internal-combustion engines may be built in an almost endless variety of types in addition to the gasoline-burning, four-cycle, poppet-valve, spark-ignition type common to modern American passenger cars. Other engines may differ from the type just described in the character of valve mechanism used, in the "cycle," in the method of compressing the charge, in the way the gases are ignited or in various other design elements.

Two-cycle engines, already mentioned, differ from the four-cycle type in that the six events composing the cycle are performed during two strokes of the piston and one revolution of the crankshaft. Power is developed during each downward stroke of the piston instead of on alternate downward strokes. In the sleeve-valve engine, sliding sleeves, operated by small cranks whose motion is similar to the reciprocal motion of the piston, are used to control admission and exhaust of the gases. Other engines have rotary valves consisting of flat discs which open and close the valve ports as they go round and round by means of openings in the disc which register with the ports as they travel past them. Still other engines mix the fuel inside the cylinder and ignite the combustible gases by compression. These compression-ignition engines are commonly called diesels, after Dr. Rudolph Diesel who completed the first successful powerplant of this type in 1897.

Capable of burning low-volatility fuels and long adapted chiefly to stationary and large marine uses, the diesel has had widespread adoption for tractor use in the last decade and has made definite, though numerically limited, progress in motor truck and bus applications.

The diesel differs from the spark-ignition gasoline engine in two major respects: (1) In the gasoline engine, as explained, the fuel and air are mixed in a carburetor *before* they enter the cylinder.

In the diesel, the fuel is fed into the cylinder by a fuel-injector and is mixed with air *inside* the cylinder. (2) The gasoline engine compresses a *mixture* of gasoline and air which is ignited by an electric spark. The diesel engine compresses *only a charge of air* and ignition is accomplished by heat of compression. In a diesel the " compression " is far above that used in any spark-ignition engine, thus enabling it to convert more of the energy in its fuel into work than does the gasoline engine. The diesel burns fuels much less volatile than gasoline and produces more miles per gallon in a motor vehicle than does the gasoline engine because of its higher thermal efficiency.

Against the diesel, as compared to the spark-ignition engines used in modern passenger cars, are its higher weight-to-horsepower ratio, its greater starting difficulties, its higher first cost, and its probably higher maintenance cost.

Cylinder Arrangements.—Automobile engines also vary in the arrangement of cylinders in the cylinder block. Most passenger-car engines of less than eight cylinders — and many with eight cylinders — are of the " in-line " type in which the cylinders are arranged in a straight line, one behind the other, with the crankshaft located directly below them. Many eight-cylinder engines and practically all twelve- and sixteen-cylinder automobile engines are of the V-type in which the cylinders are arranged in two banks to form a V with the crankshaft as the bottom point. Usually the angle of the V is 90 deg with eight-cylinder engines; 75, 60 or 45 deg for twelve-cylinder engines; and 45 or 135 deg for sixteen-cylinder engines.

Crankshafts for V-type engines generally have only half as many cranks or throws as there are cylinders, since two connecting rods (one for each bank) generally are connected side by side to each crankpin.

" Pancake " or horizontal-opposed engines have the cylinders laid on their sides in two rows with the crankshaft in the center. This type has the advantage of saving height and, for this reason, is found in trucks and buses of the cab-over-engine type or with the engine mounted under the body.

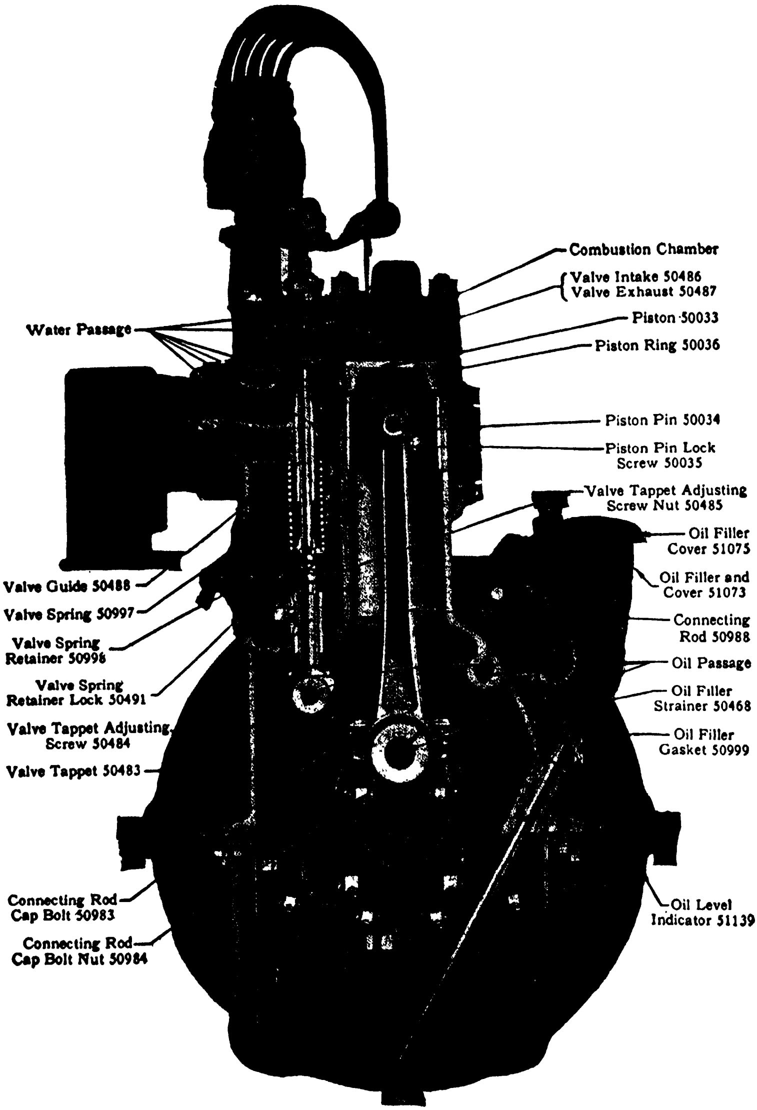


Fig. 18 — Engine parts

CHAPTER V

THE ENGINE — ITS PARTS AND CONSTRUCTION

Separate and detailed description of each of the parts essential to the operation of a passenger-car engine will make clear the function and construction of each one. Fig. 18 shows the locations and arrangement of these essential parts in a typical passenger-car engine.

Cylinder Block, Cylinder Head and Crankcase. — These three parts form the foundation and main stationary body of the automobile engine and serve as support and enclosure for moving parts.

The cylinder block contains: (1) the smooth, round cylinders in which the pistons slide up and down, (2) the ports or openings for the valves, and (3) passages for the flow of cooling water. The cylinder surfaces are given a precision " mirror " finish by accurate grinding and honing processes. In all modern passenger-car engines, the cylinders are cast in a single block of gray iron, although removable liners of special hardened steel sometimes serve as cylinder walls.

Cylinder blocks are classified by shape and design. The general classifications are " L " head, " I " head, " T " head and " F " head according to the arrangement of the valves. " L " head and " I " head or " overhead " designs have predominated in American practice for many years.

In an " L " head design, both inlet and exhaust valves are on one side of the engine (Fig. 19, left) and are operated by a single camshaft. " I " head engines have the valves in the cylinder head (Fig. 19, right) and are operated by push-rods operating rocker arms. The " T " head designs have the inlet valves on one side and the exhaust valves on the other side (Fig. 19, center), necessitating two camshafts. The " F " heads have one valve, usually the inlet, in the head and the exhaust valve in the cylinder block, directly opposite, and employ one camshaft.

The space above the piston when it is at its uppermost point is called the combustion chamber or clearance.

The cylinder head, a separate casting bolted to the top of the cylinder block, contains the combustion chambers, has mounted in it the spark plugs and sometimes the valves, and, for the flow of cooling water, incorporates passages which register with those of the cylinder block. The cylinder head is usually made of gray iron or

aluminum alloy and is cast separately from the cylinder block to make possible its removal for cleaning carbon and grinding valves. To retain compression in the cylinder, a flat piece of copper and asbestos (or steel and asbestos) called the cylinder-head gasket is placed between the cylinder head and the cylinder block. Holes are cut in this gasket for the studs holding the cylinder head to the block, for the passage of water from the block to the cylinder head and for the combustion spaces.

The crankcase acts as the base of the engine. It supports the crankshaft and camshaft in suitable bearings and provides the arms or brackets for supporting the engine on the frame.

Although the cylinder block and the crankcase must be considered as separate parts from a functional standpoint, physically the cylinder block and the upper half of the crankcase usually are cast as a single integral unit. This combined cylinder block and crankcase casting usually extends a short distance below the centerline of the

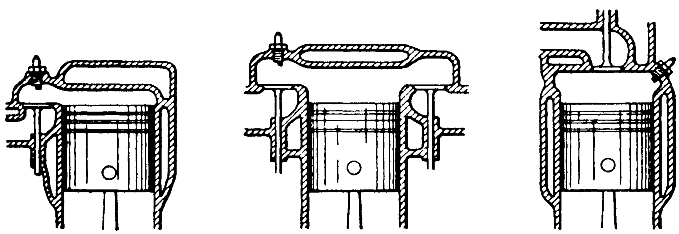


Fig. 19 — Valve arrangements

crankshaft as can be seen in Fig. 18. This casting usually is made of a ferrous alloy or " semi-steel " to provide a stronger, harder casting which will give greater wear resistance than does a gray iron casting such as commonly was used for many years. Use of this stronger, tougher material permits thinner casting walls, thus saving weight and improving cooling, although it is more difficult to machine than is gray iron.

The lower part of the crankcase is called the oil pan. It provides a reservoir for the storage, cooling and ventilation of engine lubricating oil and encloses the lower part of the crankcase. The oil pan is bolted or screwed to the lower flange of the main casting (Fig. 18) and usually is made of pressed steel or aluminum.

Engine Mounting. — Automobile engines usually are attached to the frame at two, three or four points, according to the type of mounting employed. A flexible or elastic medium, such as rubber or springs, usually is interposed between the crankcase and the frame at each mounting point to insulate the automobile frame and body from vibration and noise.

So-called "floating power" is a method of mounting engines in which only two rubber supports are used—one at the front and another at the rear of the engine. The front support is located sufficiently above the rear support so that a line drawn through the centers of the front and rear supports passes through the center of gravity of the engine. On some designs, a stabilizing spring is used to help the two rubber mountings absorb the engine vibration.

Piston.—Pistons are slightly smaller in diameter than the bore of the cylinder. The space between the piston and the cylinder wall is called the piston clearance. This clearance is necessary because the piston reaches a higher temperature than the cylinder walls, since the walls are cooled by the water surrounding them. Clearance is necessary also to provide a space for a film of lubricant between the piston and the cylinder wall.

The amount of clearance needed depends upon the size of the bore of the cylinder and the metal used in the piston, different metals having different rates of expansion and contraction when heated and cooled. Pistons are made of aluminum alloys, cast steel, cast iron, or chrome nickel, and in modern cars usually have their surfaces "anodized" or treated with a coating of tin or zinc oxide.

(Anodizing is a treatment given the surface of the piston to resist wear in which the piston increases its diameter slightly—about 0.0003 in. In this process the piston is made the "anode" in an electrolytic bath of sulphuric-acid solution.)

Aluminum-alloy pistons usually are lighter than other types and are excellent conductors of heat, but they expand more and, consequently, require some means of compensating for this characteristic. To achieve this compensation nearly-vertical slots are usually cut in aluminum pistons, so that expansion, when it occurs, takes place chiefly in the slots, leaving sufficient clearance for safe operation between the cylinder wall and the piston. Further compensation for expansion is provided in some designs by making the cross-section of the piston skirt oval. As the piston expands, the oval skirt tends to become round.

Fig. 20 shows the construction of a typical aluminum-alloy piston. Grooves are cut in the side of the piston for three or four piston rings which are incorporated to seal the compressed and exploded gases above the piston.

The top is called the head, the part below the ring grooves is called the skirt.

Piston Rings.—Oil helps the piston rings to accomplish their purpose of sealing the compressed and exploded gases above the piston. In turn, the piston rings prevent the oil from entering the

combustion space and causing carbon deposits on the cylinder head and the top of the piston. Piston rings also transmit heat from the piston to the cylinder walls. The top two piston rings are called compression rings and are designed to maintain cylinder pressures. The bottom one or two rings are called oil-regulating rings; they

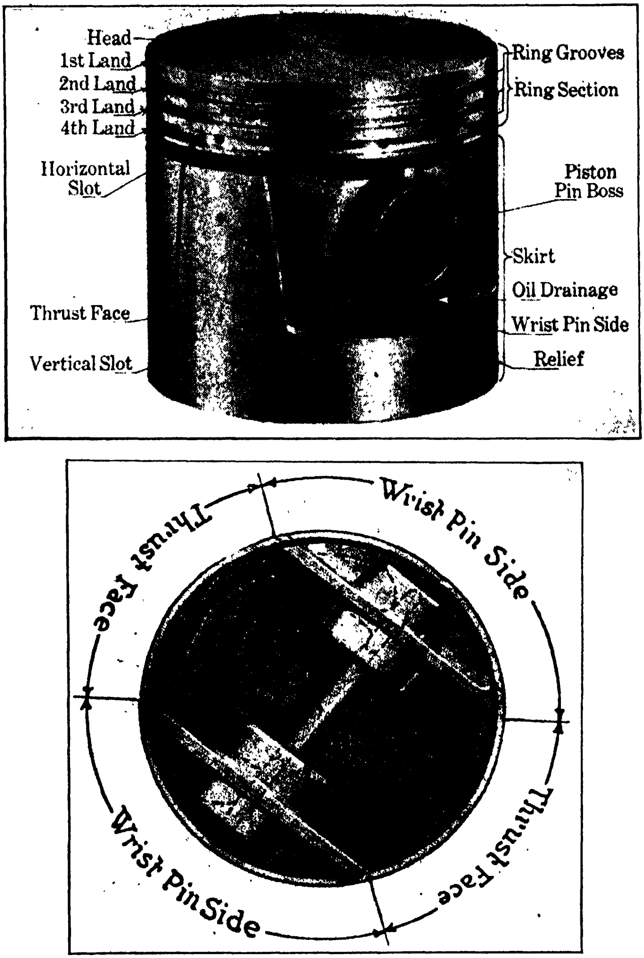


Fig. 20 — Typical aluminum-alloy piston

scrape the excess oil from the cylinder walls and return it through slots to the piston-ring grooves. From there it passes inside the piston through the oil-drain holes shown in Fig. 20.

Practically all piston rings in modern passenger-car engines are of the concentric type; that is, they are uniform in size around their entire periphery. The eccentric type, which are thicker opposite

the slot, are no longer common. Piston rings must have joints to enable them to be expanded so that they can be slipped over the piston into their grooves and to compensate for expansion and wear.

Piston rings are joined in many fashions as shown in Fig. 21. In mounting piston rings on pistons, the joints should be staggered — not placed in a vertical line — so as to prevent the compression from having a direct path to leak by the piston skirt.

Piston rings usually are made of cast iron and those used in American passenger cars are commonly plated with tin or given a surface treatment to reduce wear and eliminate scuffing. These treatments consist of special processes which change the structure of the surface layer.

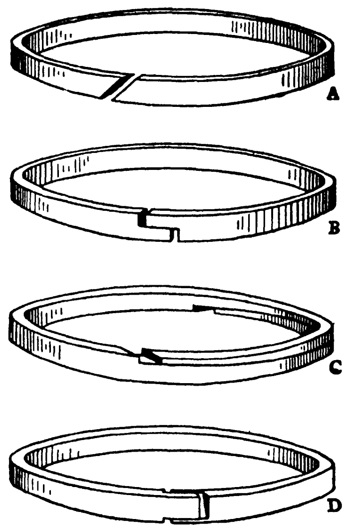


Fig. 21 — Piston-ring constructions

Piston Pin. — The piston pin or wristpin connects the piston to the connecting rod. Usually it is hollow and made of case-hardened steel.

There are three commonly used methods of accomplishing this connection:

1. The pin is fastened to the piston by setscrews through the piston boss and has a bearing in the connecting rod, thus permitting the connecting rod to swivel as required by the combined reciprocal and rotary motion of the piston and crankshaft.

2. The pin is fastened to the connecting rod with a clamp screw. In this case, the piston bosses form the bearing.

3. A "floating" pin is used which is free in both the connecting rod and the piston, but is prevented from coming in contact with the cylinder wall by two lock rings fitting in grooves in the outer end of the piston bosses.

If the piston pin is of the type that is locked in the piston bosses, a bushing of bronze or other anti-friction material is employed in the upper end of the connecting rod. When the piston pin is held by the rod only, the piston bosses carry bushings when the piston is made of cast iron; steel or aluminum pistons carry no bushings. When the piston pin is of the floating type, both rod and piston are provided with bushings in the case of cast-iron pistons.

Connecting Rod. — The connecting rod, as its name implies, is the connection between the piston and the crankshaft. It joins the wrist-

pin of the piston with the throw or crankpin of the crankshaft. The lighter the connecting rod — and the piston — the more the resulting power and the less the vibration because the reciprocating weight is less. The rod usually has an I-beam cross section. The lower part of the connecting rod (the connecting-rod head) is split to permit its being clamped around the crankshaft. The split head usually incorporates a babbitt bearing. Bearing linings of steel-backed copper-lead or steel-backed cadmium-silver also are used.

The lining may either be in the form of a separate split shell with a steel backing or it may be spun on the inside of the rod and cap

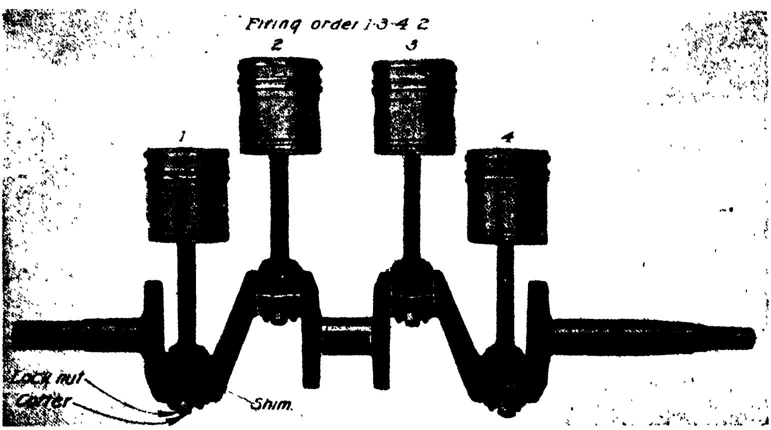


Fig. 22 — Crankshaft and piston assemblies

during manufacture of the connecting rod. When a separate split-shell liner is used, it is held in place by the connecting-rod cap and by the bolts which clamp together the split parts of the liner. A dowel pin or lip prevents the liner from turning. In the spun type of liner the babbitt is reamed to proper size at the factory.

Thin pieces of metal called shims are sometimes used when spun bearings are employed. These can be peeled or filed thinner to compensate for wear of the bearing and also to secure the correct bearing clearance between the connecting rod and the crankshaft.

Connecting rods in American passenger cars are made of steel forgings, although aluminum alloys have been used both in this country and in Europe.

Crankshaft. —The crankshaft, together with the connecting rod, converts the power delivered to the piston by the burning gases from an up-and-down (reciprocating) motion to a rotary motion (Fig. 22). The crankshaft is made from a steel forging or casting and

is machined and ground to provide suitable journals for the connecting-rod and main bearings.

The main bearings hold the crankshaft on the axis around which it rotates.

Most main crankshaft bearings are of the type employing separate split shells of babbitt backed by steel or bronze (Fig. 2). They are held in place by removable caps bolted to the crankcase. Shells of copper-lead or cadmium-silver backed with bronze or steel, designed to give longer service under high speeds, recently have appeared on several cars.

The number of main bearings varies with the design of the engine and number of cylinders. There must be at least two — that is one at the front and one at the rear of the crankshaft — and there may be as many as nine. The maximum number on a given engine cannot exceed the number of crankthrows plus one, that is, one between each crankthrow and one at each end.

The more main bearings the less possibility of vibration and distortion of a crankshaft of given size. To reduce vibration in the engine to a minimum, the crankshaft and flywheel are balanced separately and then are often tested for balance when mounted together. (In recent years a method has been developed for "dynamic" balancing the completely assembled engine as a single operation. Although individual parts and sub-assemblies are still balanced separately, the method eliminates the possibility of vibrations caused by an accumulation of slight allowable unbalances.)

Balance tests are of two kinds — "static" and "dynamic" or "running balance" tests.

In testing for static balance, the part to be tested is laid on "ways" or flat bars which are exactly level. If the part tends to roll when placed on this level surface, it is out-of-balance. To bring about balance in a flywheel, small holes are bored in the rim; in a crankshaft, metal is ground off at the throws until the part will not tend to roll when placed in any position.

But an engine crankshaft or flywheel which is in perfect static balance may not be in correct dynamic balance, because it is possible to prevent rolling on a pair of ways, yet not have the weight of all the parts or sections of the piece distributed evenly *along* its centerline; that is, it is possible to have the weight equally distributed *around* the centerline, thus giving correct static balance, and still not have the weight directly opposite another weight which balances with it. When a shaft is not balanced dynamically, it will wobble endwise, thus setting up serious vibrations in the engine.

In the upper view of Fig. 23 the parts are in correct static balance when A equals B and C equals D; but they are not in dynamic balance, because the weights which balance each other are not directly opposite, or at least nearly so. In the lower part of Fig. 23, A_1, B_1, C_1, and D_1 are all equal, hence the unit is in both static and dynamic balance.

To obtain the utmost freedom from vibration, counterweights which are exactly opposite the crankthrows are usually used. Large main bearings placed between each crankthrow also help to eliminate vibration by supporting the shaft between the points where the differing weights are balanced.

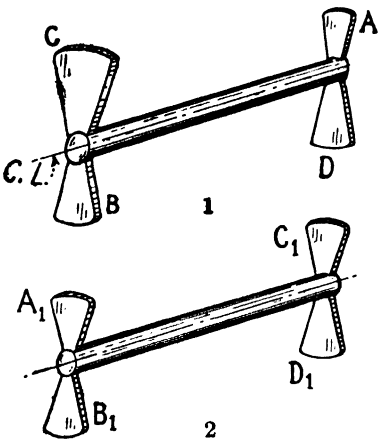


Fig. 23 — Crankshaft balancing

The parts of the crankshaft from the main bearings to the connecting-rod bearings are called the crank arms or cheeks. The length of the crank arms determines the stroke of the engine. From the center of the main bearings to the center of the connecting-rod bearings is one-half the stroke of the engine. The parts of the crankshaft inside the connecting rods are called the crankpins; those inside the main bearings are called the main journals.

Flywheel. — The purpose of the flywheel is to store up energy necessary to carry the engine over the points at which it is not receiving power impulses from the explosions. The size of the flywheel required, therefore, varies with the number of cylinders and the general construction of the engine. The flywheel is connected to the electric starting motor by a set of teeth cut on its outer rim for that purpose.

Valves and Valve Mechanism. — There are commonly two valves for each cylinder — an inlet valve and an exhaust valve. Fuel is admitted to the engine by the inlet valve and the burned gases escape through the exhaust valve. (Occasionally two inlet and two exhaust valves per cylinder are incorporated.) The valves also must seal the combustion space tightly when closed or loss of compression will result. To facilitate snug seating, the faces of the valves and the valve seats are ground at an angle, usually 45 deg (Fig. 24). This type of valve is called a poppet valve.

The valve mechanism used on a passenger-car engine depends

upon the arrangement of the poppet valves employed — whether L-head or I-head.

The poppet-valve mechanism for the L-head arrangement (Fig. 25, left) consists of the valve, valve-stem guide, valve spring, valve-spring seat, valve-spring lock, valve adjusting nut, valve lifter and valve-lifter guide.

Overhead poppet-valve mechanism used for the I-head arrangement (Fig. 25, right) consists of the valve, valve-stem guide, valve spring, valve-spring seat, rocker-arm, push-rod, valve adjusting nut, valve lifter and valve-lifter guide.

When the valve is closed, a slight clearance is necessary in the straight poppet valve between the valve lifter and the valve stem; and in the overhead poppet valve between the rocker-arm and the valve stem. This "valve clearance" allows for expansion of the valve stem and other parts as the engine becomes heated.

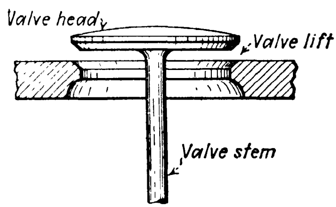


Fig. 24 — Poppet valve

Valve clearance is always figured to be more than the possible expansion of the parts, because, if sufficient clearance is not given, the valve will not seat properly when the engine gets hot and this will cause loss of power and pitting of the valves with detrimental results to the engine. It is better to have a little more clearance than is needed rather than to have too little, in spite of the slight increase in noise of the valve mechanism.

In recent years "hydraulic valve lifters" have appeared on several cars. This valve-operating mechanism prevents backlash by compensating automatically for differences in clearance and provides quieter valve operation. The hydraulic lifter is operated by means of oil which is supplied from the crankcase under pressure. When the cam turns to open the valve, a hydraulic plunger raises the pressure on the oil in a chamber and closes a check valve that traps the oil between the plunger and the valve. As the cam acts to permit the spring to close the valve, the pressure in the chamber is relieved and the check valve opens. The oil under pressure cushions the action of the valve mechanism and effects automatically any clearance adjustment necessary.

There is usually more clearance on the exhaust than on the inlet valves, because the former, exposed to the exhaust gases, are subjected to greater heat, while the inlet valve is cooled by the incoming fuel mixture.

Valve clearance differs on each engine design because it must be

varied in relation to the length of the valve stem and the material used in the valve. Exhaust valves in modern passenger-car engines are made usually of "silchrome" steels, which are special alloys high in silicon and chromium, with unusual resistance to heat. In-

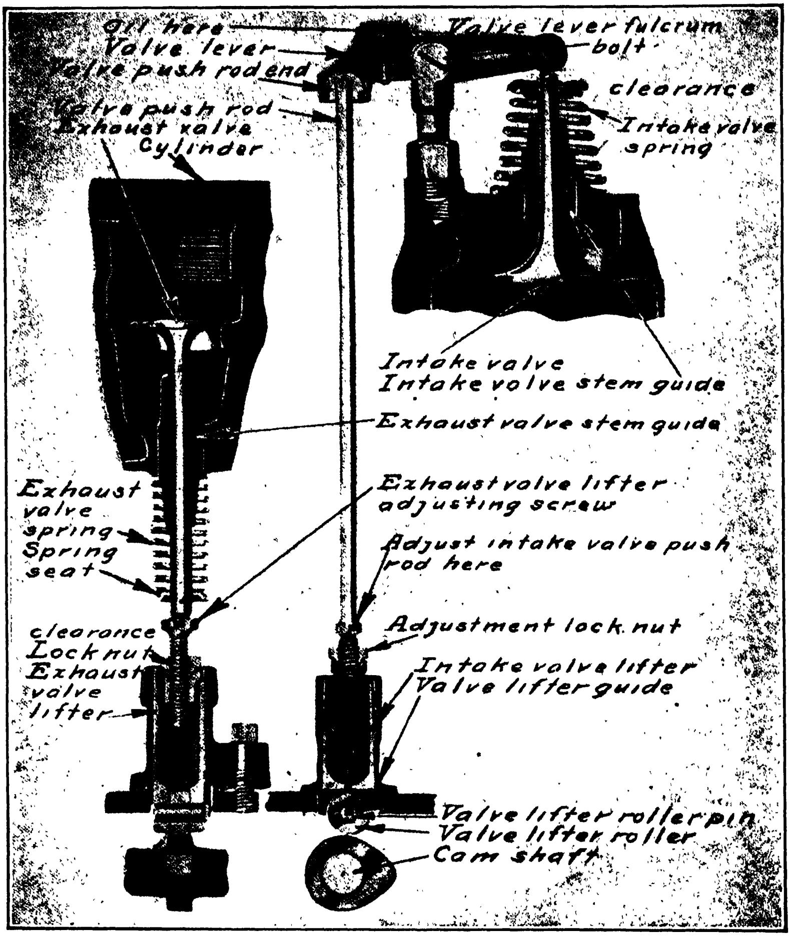


Fig. 25 — Valve operating mechanisms

take valves, being subject to less heat, are generally made from nickel-chromium alloy steels.

Exhaust-valve seat inserts are often pressed into the cylinder block to reduce wear, prevent leakage, and reduce the frequency of valve grindings. Inserts are rings of special alloy steels, and are replaceable if necessary. Usually they are used only as exhaust-valve seats.

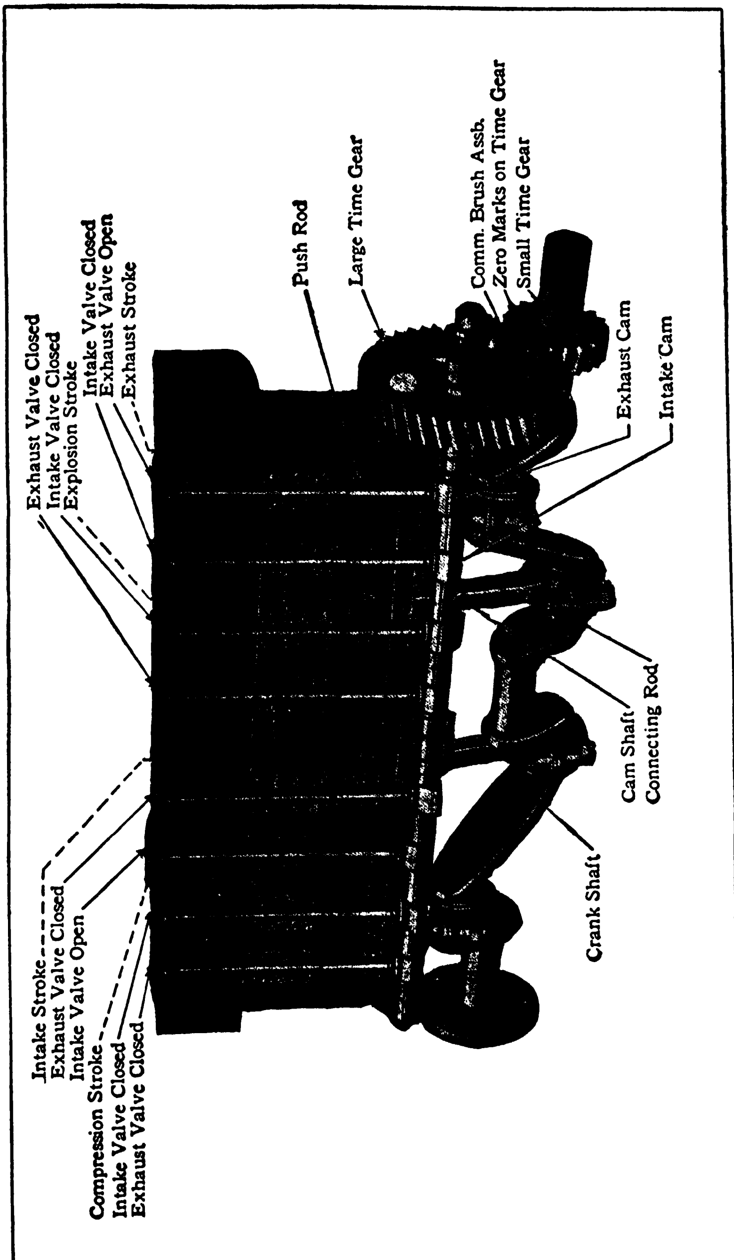


Fig. 26 — Camshaft operation

The movement of the valves is actuated by an eccentric projection, called a cam, moving on a rotating shaft — the camshaft. As the camshaft turns, the cam lifts the valve, but the closing of the valve depends upon a spring. These valve springs must have considerable tension to make the valves close promptly and prevent them from jumping away from the cams, especially at high engine speeds.

Sleeve Valves. — Although they disappeared from the engines of American passenger cars, trucks and buses in 1932, sleeve valves still hold much interest as a fundamental type of valve mechanism

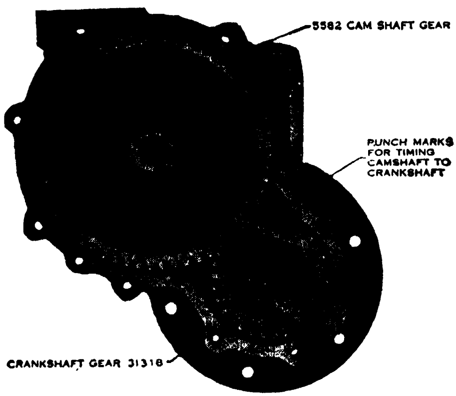


Fig. 27 — Timing gears

and because they recently have been brought to a high state of development and have found wide usage in aircraft engines in England. They are designed to provide a quieter valve mechanism, to eliminate valve grinding, and to minimize leakage. The valves formerly used in American cars are made up of two concentric cylinders or sleeves which are made to slide up and down between the piston and the cylinder wall. Slots in these sleeves register with one another at suitable intervals, providing and closing off openings into the combustion chamber to admit fresh charge and to exhaust the burned gases. This action is essentially the same as that of poppet valves except that it is achieved in another way. These sleeves are driven up and down by rods that receive their reciprocating motion from a special eccentric shaft.

Aircraft engines usually employ single sleeve valves instead of the double sleeve valve just described. The ports or slots in the single sleeve register with ports on the sidewalls of the cylinder. The sleeve operates with an elliptical motion, a combination of reciprocating and rotary motion.

Camshaft. — The camshaft, as previously indicated, is responsible for opening the valves. It carries one cam for each valve to be operated and the distance the valve is lifted is determined by the distance that the lobe of the cam projects above the rounded base of the cam (Fig. 26).

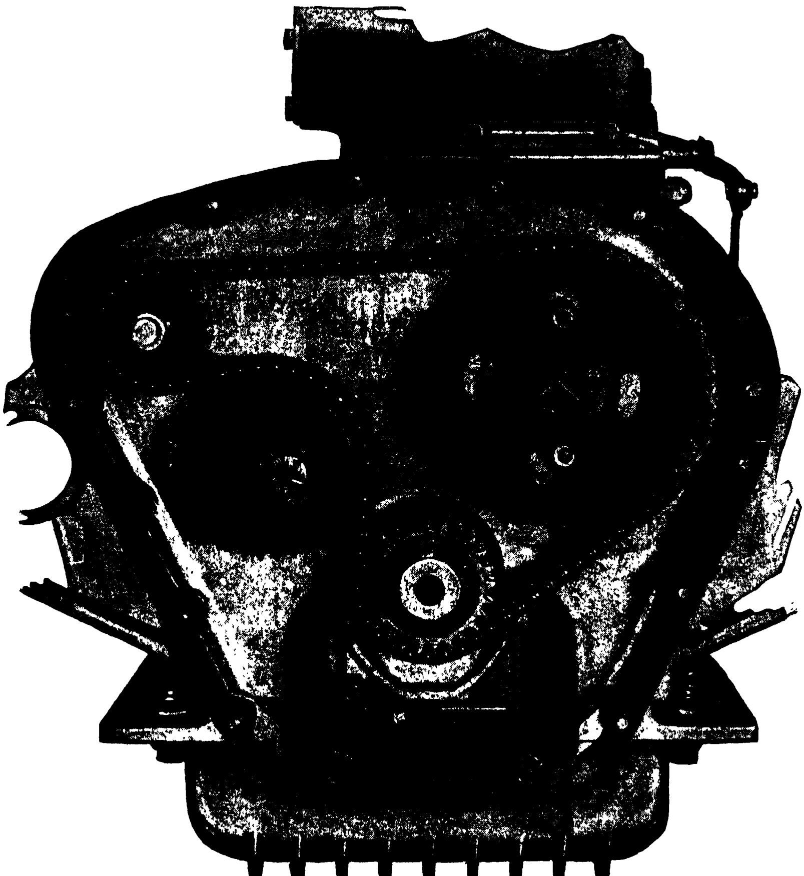


Fig. 28 — Timing chain arrangement

The rotation of the camshaft is actuated by the crankshaft through a set of gears or chains (Figs. 27 and 28), by means of which the camshaft is made to operate at ½ the speed of the crankshaft.

Other Engine Parts. — In addition to the foregoing important parts of an automobile engine are such units as spark plugs, ignition devices, carburetors, and manifolds which are discussed later under special headings.

In recent years, these parts essential to the operation of an engine have been supplemented by the addition of a number of accessories such as air cleaners, oil filters, automatic chokes, automatic heat controls, and other devices, some of which have come to be standard equipment on many cars. These additional units are treated on later pages in the context most suitable to a clear understanding of them.

CHAPTER VI

ENGINE TROUBLES AND REPAIRS

All parts of the engine are so closely related in their operation that discussion of repair and adjustment of a single part cannot be explained without simultaneous consideration of related units. Causes of and remedies for engine troubles, therefore, can best be discussed in reference to the following six groups of engine parts:

1. Connecting-rod assembly (including connecting rod, connecting rod-bearings, wristpin and bearings, piston, cylinder wall, and piston rings).
2. Crankshaft, main bearings, flywheel and crankshaft gear or sprocket.
3. Valve mechanism (including valves, valve guides, springs, seats and inserts, valve lifters and adjusting screws; rocker arms and push rods for overhead valves; hydraulic valve lifters; camshaft, camshaft bearings, and camshaft gear or sprocket).
4. Cylinder head and cylinder block.
5. Oil pan.
6. Ignition system, cooling system, fuel system, lubrication system, starting and generator systems.

Connecting-Rod Bearings are loose when too much clearance occurs between them and the crankpin on the crankshaft. When this condition exists, there will be a light-heavy knock. The loose bearing can usually be located by " shorting " out the spark plugs one at a time, with a wooden-handled screw driver. The shorted spark plug that lessens the knock is in the cylinder with the loose connecting-rod bearing. A loose bearing can cause the crankpin to wear more rapidly to an " out-of-round " or " egg " shape since each time it knocks there is added wear and strain on the same points of the crankpin with each revolution of the crankshaft. Another result of a loose bearing is that the greater clearance between crankpin and bearing is filled with an excess of oil from the oil line, which is splashed from the sides of the bearing up on the cylinder wall. This excess oil is too much for the piston rings to keep from getting up into the combustion chamber, where it is burned with the gasoline and wasted.

A worn or loose connecting-rod bearing is caused by inadequate lubrication, resulting from a lack of oil in the oil pan; oil pump supplying insufficient oil because its operation is faulty or because the oil lines are clogged; clogged oil dipper; or by an out-of-round crankpin or connecting-rod bore; by a bent or twisted connecting rod; by a bearing fitted too tight to the crankpin; or by oil of unsuitable viscosity. If not repaired promptly, loose connecting-rod bearings may crack and fall out, seriously damaging the crankshaft because the exposed steel bore of the connecting rod would then score or mark the crankpin. A bearing that gets no oil at all will "burn out" in a few miles of driving, the friction causing the babbitt bearing lining to become so hot that it will melt away into the oil pan.

A connecting rod with the spun type of bearing may be adjusted to the specified clearance by inserting or taking out an equal number of shims from each side of the bearing.

The insert or removable type of bearing has no adjustment. When this bearing wears, it is simply replaced by another of standard size if the crankpin is still true and of original size. Often, when the crankpin is worn or out of round, it is advisable to regrind the crankpin to a smaller size and install a new undersize bearing insert. Unlike the spun type, insert-type bearings may be replaced without removing the connecting rod. Undersize bearings are manufactured in stock sizes for convenience.

In the Ford V–8 one bearing insert assembly is used for two connecting rods on one crankpin. The bearing turns in the rod bores and on the crankpin. Babbitt bearing metal is on each side of the insert, and there is clearance between the bearing and the connecting-rod bores and the bearing and the crankpin.

A great help in locating bearings with too much clearance is an oil pressure tank, which supplies oil under pressure through all the oil lines of the engine. It is attached after the oil pan has been removed. By watching all the bearings, it can be seen which bearings leak too much, or which bearings do not leak enough, indicating too tight a fit or a clogged oil line.

Connecting-rod bearing clearances should run between 0.0005 and 0.003 in. Bearing end play should run between 0.0025 and 0.014 in.

Connecting Rods. — Whenever connecting rods are removed from the engine, they should be tested for alignment. This is done in a piece of equipment called a connecting-rod aligner. Bent or twisted rods may be straightened in the aligner with a bending iron. Bent or twisted rods will cause rapid bearing, cylinder, ring, piston, and pin wear, because of their tendency to oppose the vertical travel

of the pistons in the cylinders. A connecting rod with a double bend or offset may cause the piston-pin hole to be offset from the crankpin hole, but yet be parallel to it. This double bend will cause the same damage as the single bend, and should be corrected in the same way.

Wristpins or Piston Pins. — When a piston pin wears or becomes loose in the piston and connecting rod, it causes a high pitched sharp double knock at each end of its stroke. It can usually be located by " shorting " out the spark plugs, one at a time. When the knock increases in intensity, it is an indication that the loose pin is in that cylinder. The sound of the knock can be confused with the knock or tap of a valve with too much clearance between it and the adjusting screw.

The only way to correct this condition is to remove the piston and connecting-rod assembly. If the piston is made of cast iron, the pin lock screw or rings which hold the pin in place may be taken out and the pin easily removed. The bushings, whether in the piston or in the connecting rod, may be pressed out, and new standard-size bushings installed. The bushings are then reamed or honed to proper fit for a new standard-size piston pin. All pins, whether fitted to bushings or direct to aluminum pistons, have clearances between 0.0001 and 0.0009 in.

When steel alloy pistons are used, the piston pin is fitted in exactly the same way, although bushings are not used in these pistons. An oversize pin may be used by reaming the connecting-rod bushings or the steel piston bosses to the necessary size.

Fitting piston pins to aluminum-alloy pistons differs from fitting them to cast-iron or steel pistons. Since no bushing is used in the aluminum piston, the standard or oversize pin is fitted direct to the piston bosses by reaming them to the same clearances recommended for the iron pistons. The aluminum piston expands more than the pin when heated to engine running temperature. For this reason, the car manufacturers recommend that the piston be heated to temperatures ranging from room temperature to 212° F while the piston pin is being fitted. As with the cast-iron pistons, some connecting-rod upper ends are fitted with bushings, and some with a locking screw.

Piston-pin wear, bushing wear, and piston-boss wear are to be expected after long service, and when it occurs these parts must be repaired or replaced. Rapid wear is caused by too much or too little clearance, a bent connecting rod, lack of oil, or a loose pin clamp screw.

Pistons and Cylinder Walls. — There are no adjustments for

piston or cylinder wear. There are several processes for building up collapsed pistons that restore them to their original diameter.

Piston and cylinder walls will eventually wear out of round and become tapered. After a car has been driven 40,000 or 50,000 miles, this wear begins to produce high oil consumption and perhaps a piston slap or knock, as the clearance between the piston and cylinder becomes greater than originally specified. The more the piston slaps against the cylinder wall, the more it will wear. A loose piston will cause " oil pumping "; that is, on the intake stroke, when the pressure above the piston is less than atmospheric pressure, the oil will pass by the piston to try to fill the partial vacuum in the combustion chamber, and will therefore be burned and wasted. Oil consumption caused by piston rings will be discussed later.

A piston slap, sounding somewhat like a rattle, can be confused with other engine knocks. It usually can be heard on a slow pull. It can also be heard when traveling at an even speed around 30 to 50 mph.

When this condition exists, it is necessary to enlarge the cylinder and install new oversize pistons and rings. Pistons are manufactured in various oversizes for replacement in cylinders that have been enlarged. Special equipment for enlarging the cylinder bores for oversize pistons by means of honing or boring the cylinder is available through automotive equipment jobbers.

All cylinder manufacturers do not specifically state just how much a cylinder can be tapered or out of round before it should be enlarged. Installation of oversize pistons is recommended if the cylinder bores are tapered or out of round from 0.005 to 0.010 in. or over, but mostly above 0.005 in. The amount that a cylinder is tapered or out of round can be measured with a dial gage made for the purpose.

Rapid piston and cylinder wear may be due to too much or too little clearance; to a bent connecting rod; to oil not being delivered to the cylinder wall; to a piston pin fitted too tight; to too much vertical clearance of piston ring; to a broken piston ring; to a collapsed piston skirt; or to a cylinder-head gasket protruding over the cylinder bore and interfering with piston travel.

Piston Rings. — The two reasons for replacing piston rings are excessive oil consumption and loss of compression. Either one of these difficulties can be the result of several other engine troubles. To be certain that piston rings are responsible, the following test should be made: Take all the spark plugs out and open the throttle wide; insert a compression tester in the spark plug holes, one at a time, while turning the engine over with the starter. The reading

on the compression tester should be within 5 or 10 lb per sq in. of the specifications for that engine. If the reading is more than 10 lb per sq in. below specifications, it shows that either the rings, cylinder-head gasket or valves are the cause of a compression leak. To prove that faulty rings are the cause, a little heavy oil should be poured over each piston and the compression test made again. If the test shows up to specifications, the rings are to blame, because the oil acted as a seal for the rings.

Since installation of new pistons has been discussed previously, only the installation of the rings will be considered here. Piston-ring manufacturers differ somewhat as to just how much taper a cylinder may have to have their rings function properly. Depending on the design of oil and compression rings, recommendations are that oil pumping and compression can be taken care of by new rings in cylinders ranging in taper from 0.005 to 0.025 in. However, some ring manufacturers state that new pistons should be installed when cylinder taper exceeds 0.008 to 0.010 in.

Piston rings may be obtained in sets for the particular engine being worked on. They come ready to install without filing, to fit cylinders ranging in taper from 0.000 to 0.010 in., from the standard size of the cylinder. Other sets may be obtained 0.010 to 0.020 in. and 0.020 to 0.030 in. oversize rings for oversize cylinders.

Ordinarily, piston rings can run more than 25,000 miles before they need replacing. Rapid wear of the rings is caused by the oils not reaching the cylinder walls; a gap clearance that is too small; a bent connecting rod; a ring-groove clearance that is too great; dirty cylinders; and too much raw gasoline in the cylinder, which will keep the oil from lubricating the cylinder wall.

Crankshaft, Main Bearings, Etc.—Crankshaft-journal and main-bearing wear is very much like connecting-rod bearing and crankpin wear. The same general causes of lack of oil, dirt, out-of-round bearings or journals will also cause rapid wear. The knock caused by loose main bearings is a little heavier-sounding than for the connecting-rod bearings. It usually can be detected on a heavy pull above 30 or 35 mph, or at idling speed.

As explained previously in the discussion of connecting rods, the oil-pressure leak detector will show up any oil leaks in the main bearings.

Practically every car today has the insert type of main bearings. With some engines the main bearings may be replaced without removing the crankshaft; with the others, it is necessary to remove the engine and crankshaft.

If a new bearing is the correct size, the engine will crank over with a drag with a shim between bearing and journal of the thickness recommended by the manufacturer for oil clearance, and will crank over easily after the shim has been removed. If the engine cranks over easily with the shim in the bearing, it indicates too much oil clearance, and the standard-size bearing will not be correct. Excessive clearance is caused by a worn crankshaft journal. To compensate for it an undersize bearing must be used. Undersizes of 0.001 to 0.002 in. usually are fitted when the crankpin is slightly worn, but not out of round. For use when wear is extensive, other undersizes from 0.01 in. up are available in stock sizes. The crankpin is ground to the proper diameter. All crankshafts that have been taken out should be tested for out-of-roundness and taper. Some engine manufacturers recommend installing a new crankshaft if the journals are found to be worn more than 0.0005 to 0.001 in. Others recommend grinding or machining as just described.

While the crankshaft is out of the engine, it should be tested for alignment. If it is bent, it can be straightened in a heavy-duty press.

Oil should be applied to the bearings before replacing the crankshaft.

Main-bearing clearances run between 0.0005 and 0.0035 in. End play of the crankshaft as specified by manufacturers runs between 0.001 and 0.012 in. The end play or thrust is taken by one of the main bearings. If it is excessive, the bearing will knock at various speeds; this knock sometimes can be noticed when engaging or releasing the clutch. The remedy is a new main bearing.

A loose flywheel will cause a heavy single knock which can be detected by racing the engine slightly, then turning off the ignition switch. Just when the engine is about to stop, turn on the ignition switch and, as the engine " catches hold," the flywheel knock will be heard. To tighten the flywheel on the crankshaft, the clutch has to be removed. Before the flywheel is removed, two punch marks should be made side by side, one on the flywheel and the other on the crankshaft. When replacing it, these punch marks should be lined up. This procedure is necessary to preserve the balance of the flywheel and crankshaft assembly provided by the manufacturer and to maintain the accuracy of the timing marks stamped on the flywheel.

A loose vibration damper or crankshaft gear or sprocket can be heard as a thump or clatter when the engine is allowed to idle very unevenly, which can be done by shorting out a spark plug. Vibration dampers can be tightened or removed. In some cases it first

may be necessary to remove the radiator. Although vibration dampers give very little trouble, car manufacturers recommend installing new ones when trouble does occur. Timing marks, similar to those on the flywheel, are stamped on the vibration damper, and the same care must be observed to locate them correctly for timing when replacing a damper. Depending on the manufacturer's recommendations, the crankshaft gear or sprocket is removed either with the crankshaft or after it has been taken out. Punch marks are stamped on the two timing gears, and these marks must be kept in proper relationship to each other so that the valve timing will be correct.

Valve Mechanism. — Valve troubles can cause loss of power by producing loss of compression, and weak or lean gasoline mixture.

The clearance between the valve stem and the valve lifter clearance adjusting screw must be kept at factory specifications. If the clearance is too great, there will be an audible valve " tap." Too little clearance may cause a burned valve face because not enough time is allowed for the valve to cool itself by transfer of heat through the valve seat to the water jacket. The valve adjusting screw should be turned to give the proper clearance, using a " feeler " gage. Most valves are adjusted when the engine is hot. Overhead valve clearances have a range as follows: intake, 0.006 to 0.015 in.; exhaust valves, 0.008 to 0.015 in., all hot. L-head valve clearances are between the following limits: intake, 0.006 and 0.013 in.; exhaust, 0.008 and 0.013 in., all hot. For several L-head engines both intake and exhaust valves are adjusted cold between 0.0125 and 0.016 in.

Special long-handled open-end wrenches are used for adjusting the clearance screws on L-head engines. A special combination socket wrench and screwdriver is employed for adjusting clearance of overhead valves.

Sticking valves do not close all the way due to a sludge or gummy formation on the valve stem just under the valve head. This formation causes the stem to stick in the guide before it has closed entirely, causing a compression leak. By removing the valve coverplate, the open valve usually can be found. The remedy, of course, is to take the valve out and clean it.

A weak or broken valve return spring will cause loss of power because the valve will not be returned to its seat as soon as it should. It also may cause a rattle. A broken spring can be seen.

A test with a compression gage (explained previously under piston rings) will show loss of compression due to valves that are not correctly seated. This indicates that the leaky valves need to be ground into the seats. Springs should be checked in a special spring

compression tester. The shop manual will tell the pounds per square inch pressure the springs should show at various lengths. If the readings are not within the limits specified, a new spring must be installed.

There are two usual methods of grinding the valves. One is to grind them directly to the seat with a hand grinding tool and grinding compound. The other method is to reface the valve in an electric valve-refacing machine. After refacing, the valve is then ground into its seat. Care must be taken that the refacing machine is set for the proper valve face angle.

In conjunction with both of the foregoing methods, if the valve seat is found to be very much pitted and in bad condition, it will be necessary to bring it back to its original condition with a seat cutter or grinder. After restoring the seat to good condition, the valve is ground into it as explained. Valve-seat inserts are always trued up with a grinder, and the refaced valve installed directly without use of grinding compound. There is on the market a tester designed to check the seating of valves. It is placed over the valve, closed, and air is pumped into it. A dial shows whether or not the air is leaking past the seat of the valve.

Before replacing the valves, the guides should be checked for clearance. Intake valve-stem clearances run between 0.0006 and 0.00375 in., and for the exhaust between 0.0006 and 0.005 in. A quick test is to try a new valve in the guide and note by feel the difference in play between it and the old valve. If the valve is worn, it should be replaced with a new one. If the guide is worn, it should be removed and replaced with a new one.

Too much stem clearance for the intake valve will cause a weak mixture because, when the valve is open on the intake stroke, air will be sucked into the cylinder between the stem and the guide. Although a new valve or guide or both will give the correct clearance, there is on the market a part similar to a small piston ring which can be put on the valve stem to give the proper clearance between stem and guide. Other results of too much clearance are noise, bent valve, and warped valve head, the latter causing improper seating.

Although valve lifters are the source of little trouble, they can be removed easily for replacement in some engines when the valves are off the engine, by merely lifting them out. In other engines, it is first necessary to remove the camshaft, after which the lifter is removed from below.

The camshaft should last as long as the car itself, although the babbitt or bronze bearings in the cylinder block on which the cam-

shaft turns will wear eventually under normal conditions. Dirt or lack of lubrication, of course, will cause the bearings to wear faster, and possibly damage the camshaft journals. In this case, both a new camshaft and bearings would be necessary.

To replace the camshaft bearings, it is first necessary to remove the camshaft. Depending on the manufacturer's recommendations, some of the newer bearings may have to be reamed to the proper clearance; others will require no reaming. Camshaft-bearing clearances run between 0.00075 and 0.0035 in.

The camshaft end play must be between 0.002 and 0.008 in.

Occasionally the timing gear on the camshaft will need replacing due to wear or breakage. On some engines this gear may be removed without taking out the camshaft. On others, the gear must be pressed off after the camshaft has been removed from the engine. Other engines have camshaft and gear assemblies that must be replaced as a unit.

When installing the gear or sprocket and camshaft on the engine, it must be lined up carefully with the gear or sprocket on the crankshaft so that the valves will be opened at the proper time in relation to piston position. This is called "valve timing" and is discussed fully in Chapter VII.

After assembling all the parts, the valve clearances should be checked and readjusted.

Trouble with hydraulic valve lifters arises from particles of dirt around the plunger or ball check, not enough oil in the oil pan, a clogged oil line, or the wrong clearance between the valve stem and top of plunger. When it is necessary to remove the assemblies, they should be marked so that they may be replaced under the same valves. It is very important that the plunger be replaced in the cylinder from which it was removed, as these parts are fitted in matched sets at the factory for proper oil clearance. In the L-head type of valve, with the valve closed and the plunger down in the cylinder as far as it will go, the clearance should not be less than 0.030 in. nor more than 0.070 in. One make of car specifies that this clearance is taken care of automatically.

Cylinder Head and Cylinders. — Cylinder-bore and main-bearing wear having been discussed previously, this section will deal with the relationship between the cylinders and the cylinder head. The main and rare trouble that could affect the cylinder head itself is warping. A long steel scale across the machined surface will show whether the head is warped. The best remedy is to put on a new head. If the warpage is slight, the head can be machined, but not

more than enough to produce a true surface. By removing too much metal, the compression ratio specified by the manufacturer would be increased, probably affecting the efficiency of the engine. A thicker cylinder-head gasket, however, could be used to compensate for the metal removed in machining the head.

All cylinder heads, whether of cast iron or aluminum or of the L-head or the overhead-valve type, should be tightened down with a torque wrench to the manufacturer's specifications. Uneven tightening causes distortion of the cylinder block, which, in turn, will not allow the valves to seat squarely, eventually warping them with loss of compression as a result. Such distortion will also cause excessive piston, cylinder-wall, and piston-ring wear since the cylinder is not in accurate alignment with the connecting rod and crankshaft. It also is possible that the cylinder-head gasket will blow out or leak.

All cast-iron cylinder heads first should be tightened down cold when reinstalled, in the order specified by the manufacturer in regard to the nuts or cap screws. (New cylinder-head gasket should always be used.) Then tighten the nuts in the specified order with a torque wrench to the specified tightness after the engine has been warmed up for a while. Aluminum heads should be tightened only when cold.

Oil Pan. — Some oil pans are removed easily by simply draining the oil and removing the cap screws that hold it to the engine block. To remove others it is first necessary to take off the steering tie rods. For a third construction it is necessary to remove the steering rods and jack up the front end of the engine after having removed the front engine bolts; and for a fourth group, only the front engine bolts must be removed and the engine jacked up.

Except to clean it thoroughly with gasoline to get all the heavy sludge out so it will not clog the oil system, little service is necessary for the oil pan. In one make of engine copper tubing is installed in the oil pan so that oil is spurted into the connecting-rod oil dipper, thereby supplying the bearing with oil. This tubing and connecting-rod dipper must be in alignment according to factory specifications. New gaskets should always be put on the oil pan when replacing it.

Other Engine Units. — The service notes just completed are for the engine unit only. Other vitally important parts that compose the engine assembly are the ignition system, cooling system, fuel system, lubrication system, starting and generator systems. Owing to their importance, each will be taken up separately in other chapters following.

CHAPTER VII

VALVE AND IGNITION TIMING

In describing the operation of the four-cycle engine (Chapter IV), it was explained that the inlet valve is open during the suction stroke and the exhaust valve during the exhaust stroke. In this chapter will be shown the exact time at which each of the valves open and close with reference to the position of the piston, together with the reasons involved in the determination of what those exact times shall be.

During the suction or inlet stroke, the inlet valve must be open to admit the charge. The charge is sucked into the cylinder due to the pressure being reduced inside the cylinder as the piston moves downward.

Actually, in an overwhelming majority of modern cars, the inlet valve opens slightly before the piston starts downward on the suction stroke and closes after the piston has started upward following completion of the suction stroke. The reason that the inlet valve is opened before the start of the suction stroke is that both inlet and exhaust valves are made to open and close very slowly, and this timing of the opening of the inlet valve is necessary to permit this valve to be open sufficiently during the suction stroke. The valves are made to open and close very slowly to provide quiet operation under modern high-speed conditions. The timing of the opening and closing of both inlet and exhaust valves is, of course, controlled by the design of the cams on the engine camshaft.

The rapid decrease in pressure in the cylinder due to the downward motion of the piston causes the gases to rush in to fill up the space above the piston. If the piston moves slowly, the mixture will be able to enter fast enough to keep the pressure in the combustion space equal to that outside. At the high speed at which gasoline automobile engines run, however, the piston will reach the end of its downward stroke before a complete charge has time to enter through the small inlet valve opening. Therefore the pressure in the combustion space will still be below that of the atmosphere. If the inlet valve closed at this point so that no more mixture could enter, the combustion of the partial charge would exert less pressure on the

piston during the power stroke than would combustion of a full charge. The inlet valve is permitted to remain open, therefore, until the piston reaches a point in its next upward stroke (the compression stroke) at which the pressure in the cylinder equals that outside. This period varies in different designs, ranging from 28 deg to 71 deg of crankshaft turn in modern passenger-car engines. The piston moving upward diminishes the space in the cylinder and compresses the charge ahead of it. When under compression, as previously explained, the gas is ready to be ignited and burned.

The combustion of the inflammable mixture produces a certain amount of heat. The more rapid and complete the combustion, the greater and more sudden will be the rise in pressure. The pressure will be greater when the mixture is confined in a small space than when in a large space. Since the combustion space is smallest when the piston is at its topmost point, the greatest pressure will be obtained if combustion is completed at this point. If combustion of the mixture were instantaneous, it would be ignited at this point. But the combustion is not instantaneous. Even though the charge burns very rapidly, it burns slowly enough to make ignition necessary before the end of the compression stroke if combustion is to be nearly complete as the piston comes into position to move downward again. The instant at which the mixture must be ignited to produce this result depends on the speed of the piston. The interval between the ignition of a good mixture and completion of its burning does not vary to any great extent in different designs. When the piston is moving slowly, the mixture may be ignited toward the end of the compression stroke, for there will be sufficient time for complete combustion by the time the stroke is ended. When moving at high speed, as in practically all modern automobile engines, ignition must occur much earlier in the stroke, as otherwise the piston will have completed the compression stroke and begun to move downward on the power stroke before the mixture is sufficiently burned. The instant at which ignition occurs also depends on the mixture that is used, since this makes a difference in the rapidity with which it burns. The more uniformly the gasoline and air are mixed, the faster and more completely the mixture will burn and ignition may occur later in the stroke than would be possible with a less homogeneous mixture. The instant at which ignition occurs may be controlled by causing the spark to take place earlier or later. In modern cars this control is usually accomplished by two automatic devices: a speed control using a flyball governor in the distributor head and a vacuum control operated from the intake manifold.

When ignition occurs early in the compression stroke, the spark is said to be " advanced." A " retarded " spark occurs when the compression stroke is more nearly complete at the time ignition occurs.

If the spark is advanced too much, combustion will be complete before the piston has reached the end of its compression stroke. The momentum of the flywheel would then have to force the piston upward against a resulting pressure in order to get it into position to move downward on the power stroke. In such a case, the momentum of the flywheel might not be sufficient to overcome the pressure and the engine would stop or " stall."

If the spark is too long retarded, however, combustion of the charge will be completed too long after the piston has begun to move downward on the power stroke. The pressure will then be reduced because the combustion will have taken place in a larger space — and the piston consequently will be moved downward with less force. If the spark is still further retarded, combustion may not be completed by the time exhaust begins. The heat from only a portion of the mixture will then be utilized because the gases will still be burning as they are forced out of the cylinder.

The position at which the spark occurs should be governed by the speed of the engine. Suppose that efficient combustion is being produced at a given engine speed with a given spark setting. Then, if the speed of the engine is increased, there will be insufficient time for efficient combustion unless the spark setting is advanced, since combustion requires a certain amount of time regardless of the piston speed. Therefore, the spark should be advanced as the engine speed is increased.

While the high compression of the charge improves its quality and results in combustion being more rapid and complete, it has limits. If carried too far, the heat generated by the compression will be sufficient to ignite the mixture. This " pre-ignition " would have a bad effect on the operation of the engine, for the pressure then would be produced at the wrong point in the stroke, retarding instead of assisting the revolution of the crankshaft.

As the piston is forced downward by the expanding gases, it has been found necessary to open the exhaust valve before the piston reaches the end of the stroke. Even though this wastes some of the force of the expansion, the freedom afforded the piston in commencing the exhaust stroke amply compensates for the waste. By opening the exhaust valve before the piston reaches the end of its power stroke, the gases have an outlet for expansion and begin to rush out of their own accord. This removes the greater part of the

burned gases, reducing the amount of work to be done by the piston on its return stroke.

Obviously, it would be wrong to keep the exhaust valve closed up to the very moment when the piston is about to move upward, for then, when beginning the exhaust stroke, the piston would be confronted for an instant with the force which had just driven it downward — and, until the valve was wide open, there would be a considerable loss of power. If the exhaust valve opens too early, on the other hand, there is a waste of power because the gases are exhausted when they still could exert a pressure on the piston.

During the next upward stroke, the remaining gases are forced out of the open exhaust valve as the pressure in the cylinder exceeds

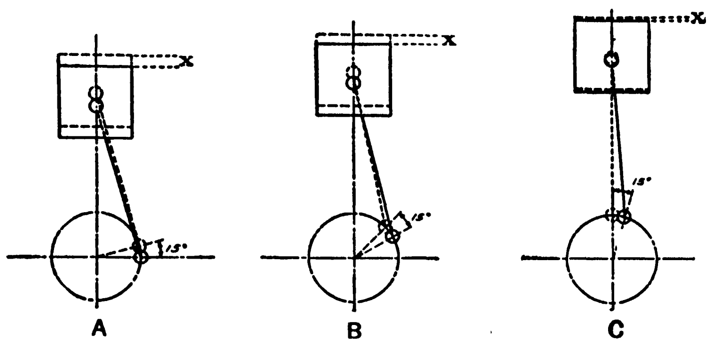


Fig. 29 — Rock of piston

that in the exhaust manifold. This causes a slight compression of the gases ahead of the piston and, when it reaches its topmost position, there will be a certain amount of compressed exhaust gases in the clearance space.

If the exhaust valve is closed at this point, a large portion of these gases will be retained in the cylinder.

The best results are obtained, not by closing the exhaust valve at the end of the exhaust stroke, but a short time after the piston has begun to move downward on the next suction stroke. This is the practice on all modern American car engines.

It might appear that this would result in drawing the exhaust gases back into the cylinder. Two conditions, however, prevent such drawing back: (1) the gases under compression exceed the pressure in the manifold and will continue to flow out due to this difference in pressure; (2) the piston, while at the top of the stroke, moves but very little for 10 to 15 deg movement of the crankshaft. This does not materially increase the combustion space, as reference to **Fig. 29 shows clearly.**

It will be seen in Fig. 29 that, when the crank arms are in a position shown at *A*, for a certain number of degrees movement of the crankshaft, the piston will move upward for a certain distance. When the crank arms are at point *B*, for the same number of degrees turning of the crankshaft, the distance moved by the piston will be less. When the crank arms are at point *C*, for the same number of degrees, there is very little upward movement of the piston. Between certain points it can be seen that there is practically no motion of the piston. Travel in this region is called the "rock of the piston." Usually it is in this region that the exhaust valve is closed after top dead-center.

The exact timing of valves of a representative group of modern passenger-car engines is shown in an accompanying table, from which comparisons may be made as to the time the valves open and close on different designs. It will be seen that the point at which the inlet valves open is somewhat different in various engines, because of difference in design.

The point at which exhaust valves open also varies and depends upon the same conditions as the closing of the inlet valve.

VALVE TIMING

	Intake		Exhaust	
	Open	*Close*	*Open*	*Close*
Buick 40 Special; 50 Super	13°B	68°A	55°B	22°A
Buick 60 Century; 70 Roadmaster; 80 Limited; 90 Limited	14°B	71°A	56°B	25°A
Cadillac V-8 62; 60S; 72; 75	DC	42°A	52°B	10°A
Cadillac V-16	6°B	28°A	44°B	12°A
Chevrolet Master 85; DeLuxe	3°B	35°A	46°B	5°A
Chrysler Royal 6-625	12°B	44°A	50°B	6°A
Chrysler 8-C 26; Crown Imperial 8-C 27	6°B	50°A	44°B	12°A
De Soto 6-S7	12°B	44°A	50°B	6°A
Dodge 6, D14; D17	6°A	46°A	42°B	8°A
Ford V-8 60	9½°B	54½°A	57½°B	6½°A
Ford V-8 85; DeLuxe	DC	44°A	48°B	6°A
Hudson 6-40; Super 6-41; Country Club 8-44, 45, 47	10⅔°B	60°A	50°B	18¾°A
LaSalle V-8 50, 52	DC	42°A	52°B	10°A
Lincoln-Zephyr 12	10½°B	35½°A	60°B	8°A
Mercury V-8	DC	44°A	48°B	6°A
Oldsmobile 6-60; 6-70	5°B	45°A	45°B	5°A
Oldsmobile 8-90	DC	35°A	45°B	10°A
Packard 110; 120	1°B	39°A	45°B	5°A
Packard Super 8	4°B	51°A	49°B	10°A
Plymouth 6-P9; P10	6°A	46°A	42°B	8°A
Pontiac 6 (40-25; 40-26); 8 (40-28; 40-29)	5°B	39°A	45°B	5°A
Studebaker Champion 6; Commander 6; President 8	15°B	49°A	54°B	10°A
Willys 440	9°B	50°A	47°B	12°A

Valve Timing Adjustments. — Ignition timing probably will be checked more than one hundred times for every time the valve timing is checked when working on an engine. They are two entirely different operations but, as previously shown, they are very much related to one another.

Manufacturers design and time valves so that they will open and close in relation to piston travel to give the maximum performance to the engine. If this relationship between valves and piston is changed even slightly, the efficiency of the engine will be lowered in one of the following manners:

Intake Valve. — Early opening and late closing are caused by having too little or no clearance between valve stem and lifter. Before the valve closes as the piston goes up on the compression stroke, some of the gas will be pushed back into the intake manifold, weakening the mixture. Late opening and early closing is caused by too much clearance between valve and lifter. In this case the valve will not be open long enough to take in the proper quantity of mixture to give full power.

Exhaust Valve. — Early opening and late closing results from little or no clearance. Since the exhaust valve opens near the bottom of the power stroke, an earlier opening than specified means wasted power. Late opening and early closing are caused when there is too much valve clearance. This condition causes an inefficient mixture, since all of the exhaust gas does not have a chance to be expelled from the cylinder, and therefore this remaining gas dilutes the incoming fresh mixture. It tends also to create a back pressure on the piston.

The foregoing conditions could happen to any one or more valves of an engine since each has its own adjustment. The effect is that the engine does not run smoothly or loses power. The more valves out of adjustment, the worse the condition would be. The remedy is to adjust the valve-stem clearances to factory specifications.

If the marks on the timing gears or sprockets are not lined up properly, all the valves will be out of time, and the engine will run very poorly, if at all. An engine equipped with timing gears and properly timed could never get out of time unless, of course, the camshaft gear or the camshaft itself should break, neither of which happens very often. Engines equipped with timing sprockets and chain rarely give trouble either. Some chains are adjustable and some are not. Chain wear eventually will change the valve timing a little. Late valve opening means that the chain is worn and should be renewed. Replacement also is the only remedy for sprocket wear.

The slack in some worn timing chains may be taken up by a sprocket, usually used also to run the generator. The timing chain sometimes gets so loose that it will "jump a tooth" or more and throw the valves out of time. This indicates that the adjustment is too loose, or the chain has worn and needs replacing. Re-timing the valves will, of course, be necessary.

Adjustment of ignition timing is discussed at the end of Chapter XVIII, following a full description of the automobile electrical system.

CHAPTER VIII

ENGINE BALANCE, VIBRATION, AND FIRING ORDER

General Considerations of Engine Balance. — When an engine is in balance, it has both " power balance " and " mechanical balance." An engine is said to be in power balance when the power impulses occur at regular intervals with relation to the revolution of the crankshaft and each power impulse exerts the same force. Mechanical balance is obtained in an engine when the moving parts, both rotating and reciprocating, are arranged so that they counterbalance in operation and thereby minimize vibration. Balance of engines having different numbers and arrangements of cylinders will be explained in detail, along with their firing orders, later in this chapter.

The rotating parts of an engine can be balanced mechanically by bringing them into " static " and " dynamic " balance as explained in Chapter V. The crankshaft and flywheel are the principal parts of an engine to be balanced mechanically.

Bringing the reciprocating parts into mechanical balance, however, is not such a simple problem. The weight of the pistons and connecting rods, moving one way and then the other, produces considerable vibration. The crankshaft is subjected to shocks in bringing these parts to a stop at the end of each stroke. These shocks on the crankshaft are called " primary inertia forces " and are increased in intensity by the gas pressure on the pistons at the end of the cycle. Some engines also have " secondary inertia forces " which will be discussed later under " Four-Cylinder Engines." In a well-designed engine every piston and connecting rod is of the same weight within accurate limits, and the flywheel and crankshaft assembly has a perfect dynamic balance. By this practice much of the vibration is minimized.

One manufacturer began in 1940 to balance dynamically every completely assembled engine, including clutch, flywheel, and accessories, thus permitting a much closer balance of the complete engine. The purpose of this procedure is to eliminate any possibility that the slight unbalance tolerated in the rotating or reciprocating parts might all be on one side, causing a " stacking up " of unbalance, resulting in vibration.

Vibration. — Every well-balanced engine must eliminate or minimize several important types of vibration either through the original design or subsequently added expedients.

" Torsional vibration " of the crankshaft is caused by the winding and unwinding (or twisting and untwisting) of the crankshaft resulting from the application and release of the power impulses on the crank throws of the crankshaft. If the crankshaft is relatively small in diameter in proportion to its length, it is obvious that this effect will be greater than for a shorter, thicker crankshaft. It can be understood that crank throws that are close to the flywheel transmit their forces to the flywheel (which resists this twisting tendency) with little twisting or crankshaft " wind-up." The crank throws at the front end of a six- or eight-throw crankshaft, on the other hand, have a considerable length of crankshaft between them and the flywheel to wind and unwind with each power impulse. As a result there is a proportionate increase in twist resulting from the power impulses on these forward crank throws. *Every* crankshaft has an inherent natural period or frequency of vibration. If the frequency of the torsional vibration caused by this winding and unwinding of the crankshaft should correspond to its natural period of vibration (be in " resonance "), the vibration would become excessive, with serious results, such as crankshaft breakage. Speeds at which resonance might occur are called " critical speeds."

A number of methods are used to minimize crankshaft torsional vibration. One is to design the crankshaft so that its basic or highest critical speed is above the maximum speed of the engine, and to damp out the torsional vibration that occurs at lower speeds by special means or by natural bearing friction. Most six- or eight-cylinder automobile engines, however, because of their relatively long crankshafts and high speeds, depend upon torsional vibration dampers to neutralize torsional crankshaft vibration. One of several types usually is mounted on the front end of the crankshaft. One type, called a " harmonic balancer " is provided with an inertia weight which is set in vibration by the torsional vibration but, because its motion is out of phase or opposite to that of the crankshaft, it tends to neutralize the crankshaft's vibration or damp it out. Another widely used type is composed of a small flywheel held between two friction discs. When the crankshaft is subjected to torsional vibration, this flywheel does not vibrate because of its mass but continues uniform rotation, and the slippage of the flywheel on the friction discs tends to damp out the torsional vibration.

Another type of vibration is caused by the " torque reaction " of

the connecting rods on the cylinder block as they push against the crankpins to cause rotary motion of the crankshaft. If the crankshaft is rotated in one direction, the torque reaction of the connecting-rod impulses tends to rotate the cylinder block in the opposite direction. Since the connecting-rod impulses are fluctuating in nature, the torque reactions on the cylinder block also fluctuate or vibrate. This type of vibration is minimized in modern passenger-car engines either by increasing the number of cylinders, or by various methods of mounting the engine on rubber so that most of the vibration is absorbed before it is transmitted to the body or frame.

Firing Order. — The sequence in which the power impulses occur in an engine is called the firing order. When the cylinders are in line, the cylinder farthest in front or nearest the radiator is designated as No. 1, the one directly behind it is No. 2, and so on. With V-type engines, the practice as to numbering the cylinders is not uniform; it will be explained later, therefore, in discussions of V–8, V–12, and V–16 powerplants.

Balance and Firing Order of Various Engines. — Although motor vehicle engines of less than four cylinders are rarely found, a knowledge of the balance and firing order of engines of one and two cylinders will aid in understanding the balance and power sequence of today's multicylinder automotive engines.

Because the one-cylinder engine has but one power impulse for every two revolutions of the crankshaft, it is evident that it will not run smoothly and quietly, in spite of the compensating effect of a large flywheel. Due to the relative large size of the cylinder and the time between power impulses, the parts must be made large and heavy to withstand the resultant rough operation. This fact has led successively to the adoption of the two-, four-, six-, eight-, twelve-, and sixteen-cylinder engines. As the number of cylinders is increased, the power impulses for each revolution of the crankshaft increase in frequency, giving a more uniform torque and smoother operation. Above four cylinders there is no period during which some cylinder is not delivering power. Therefore, in an engine having six or more cylinders, there is no time at which the flywheel must supply *all* the power required to maintain the engine speed. The more cylinders in an engine, the more continuous is the flow of power if the power impulses are spaced equally, the less is the vibration, and less work has to be done by the flywheel in storing and releasing the energy. Flywheels for multicylinder engines, therefore, can be lighter than those used in engines with fewer cylinders. Either the same amount of power can be generated by a larger number of smaller cylinders,

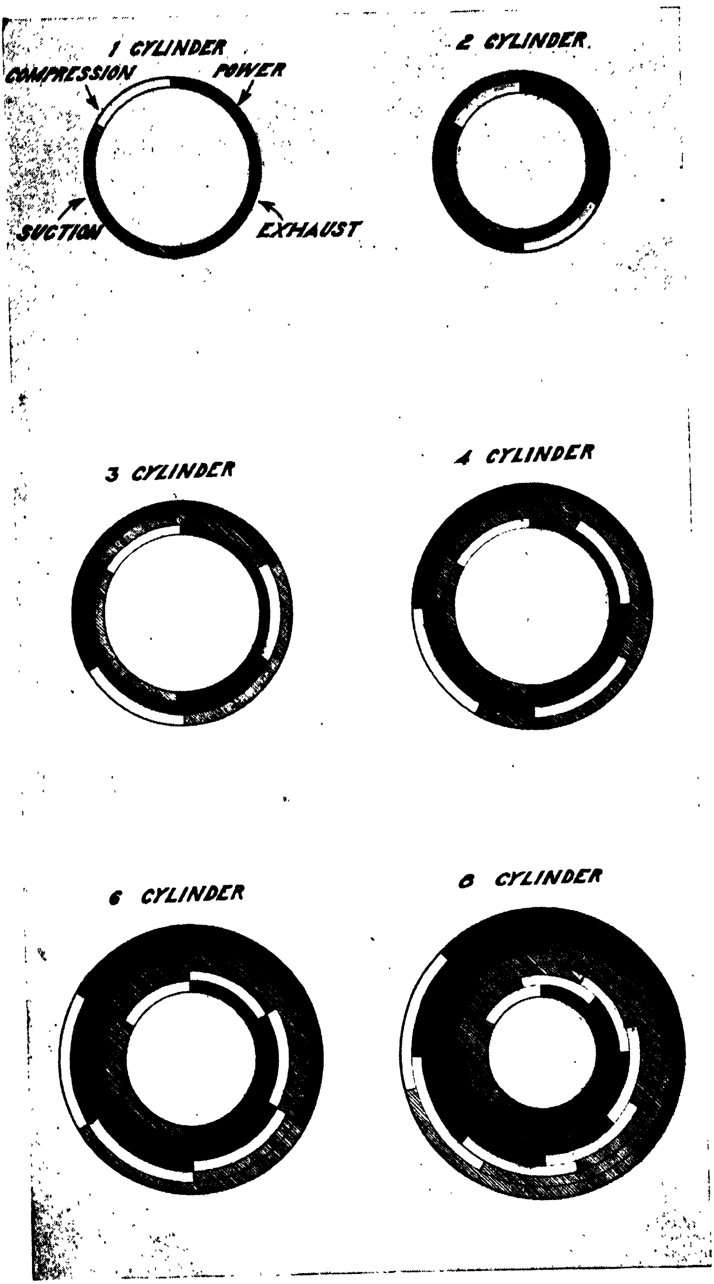


Fig. 30 — Power overlap charts

or the power output can be increased by adding more cylinders of the same size.

As was shown in Chapter VII in connection with valve timing, the length of the power impulse is about 145 deg. Fig. 30 shows graphically the power overlap of engines with various numbers of cylinders, each complete circle being 720 deg, or one complete cycle consisting of two revolutions of the crankshaft. It is obvious that, as the number of cylinders is increased, the power impulses extend over a greater range. For engines having more than four cylinders, the power impulses are continuous and overlap, the length of overlap increasing with the number of cylinders.

One-Cylinder Engines. — In the one-cylinder engine (Fig. 31) there is but one power impulse in two revolutions of the crankshaft

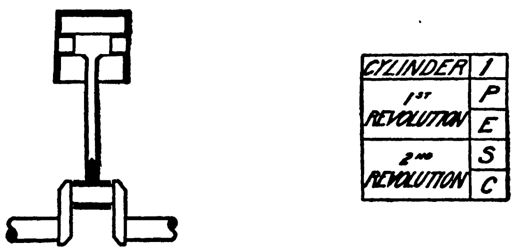
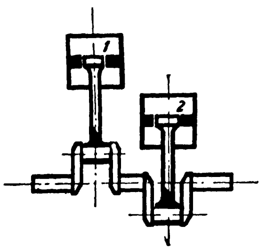


Fig. 31 — One-cylinder power-balance chart

resulting in an uneven distribution of power, as has been explained previously. Since there is but one piston and connecting rod which reciprocate with no working parts to counterbalance their weight, a one-cylinder engine does not have mechanical balance. The engine, however, can be balanced to some extent by the use of counterweights attached to the crankshaft and also by the use of a flywheel so heavy that its momentum produces a comparatively steady movement. Fluctuations in the speed of the engine will cause vibration, even in the best designs of one-cylinder engines, making this type undesirable for use in motor vehicles.

Two-Cylinder Engines. — Fig. 32 shows a two-cylinder vertical engine with a 180-deg crankshaft. When in operation No. 1 piston is moving outward as No. 2 piston is moving inward, in other words, the pistons move in opposite directions. For this reason an engine of this construction has good mechanical balance with reference to primary inertia forces. If piston No. 1 is moving downward on power, piston No. 2 can be moving upward on either compression or exhaust. In Table I the power balance is worked out with piston No. 2 moving upward on compression, and it is indicated clearly that

both power impulses occur during the first revolution of the crankshaft while there are no power impulses during the second revolution. In Table II the power balance is worked out with piston No. 2 moving upward on exhaust. This arrangement gives a power impulse at the beginning of the first revolution and at the end of the second revolution, producing the same result as obtained in Table I. In either case there is an irregular production of power which sets up vibrations in the engine and causes it to run unevenly.



I

CYLINDER	1	2
1ST REVOLUTION	P	C
	E	P
2ND REVOLUTION	S	E
	C	S

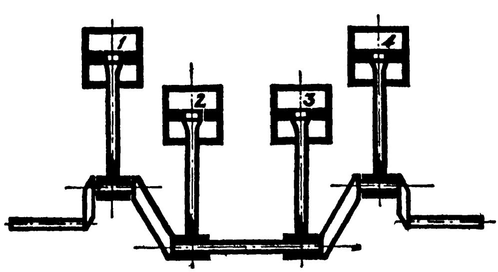
II

CYLINDER	1	2
1ST REVOLUTION	P	E
	E	S
2ND REVOLUTION	S	C
	C	P

Fig. 32 — Two-cylinder 180-deg-crankshaft power-balance chart

A two-cylinder engine that has better balance is the type using the same 180-deg crankshaft but with the cylinders horizontal and arranged on opposite sides of the crankshaft. With this arrangement the power impulses can be spaced evenly.

Four-Cylinder Engines. — With a four-cylinder engine, a 180-deg crankshaft, arranged as shown in Fig. 33, always is used. The crank arms for Nos. 1 and 4 cylinders project in the same direction,



I

CYLINDER	1	2	3	4
1ST REVOLUTION	P	E	C	S
	E	S	P	C
2ND REVOLUTION	S	C	E	P
	C	P	S	E

II

CYLINDER	1	2	3	4
1ST REVOLUTION	P	C	E	S
	E	P	S	C
2ND REVOLUTION	S	E	C	P
	C	S	P	E

Fig. 33 — Four-cylinder power-balance chart

and the crank arms for Nos. 2 and 3 cylinders project from the opposite side of the crankshaft.

In the four-cylinder engine, Nos. 1 and 4 pistons are always moving in the opposite direction from pistons Nos. 2 and 3. This arrangement tends to neutralize the primary inertia forces as, if the

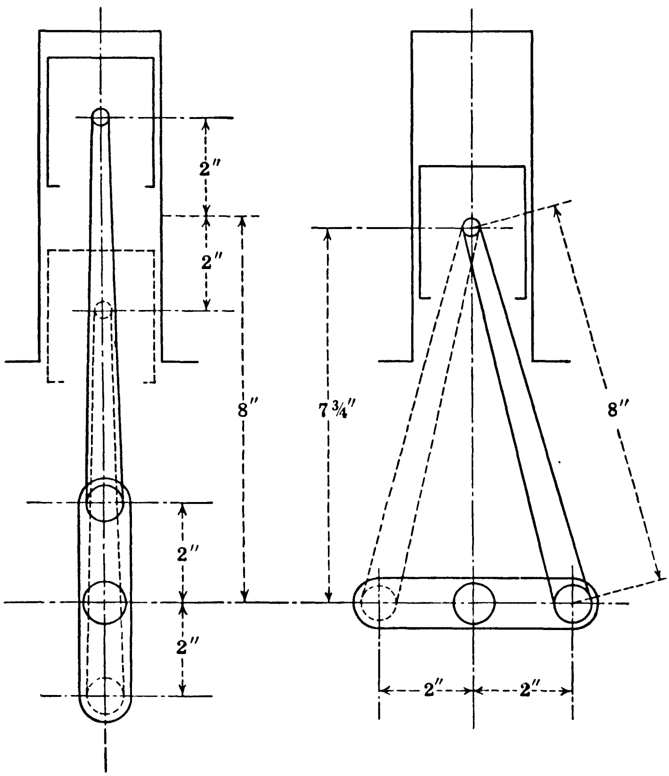


Fig. 34 — Cause of vibration in four-cylinder engines

pistons are equal in weight, they will balance each other and give good primary mechanical balance.

The four-cylinder engine, however, does not inherently provide good balance of the secondary inertia forces acting on the reciprocating parts These unbalanced inertia forces bring about what is known as " secondary vibration," and their causes can be made clear with the aid of Fig. 34, which shows the relation of the pistons and connecting rods of a four-cylinder engine as viewed from the front. The view at the left shows the crank arms vertical, with pistons Nos. 1 and 4 at the top of the stroke and pistons Nos. 2 and 3 at the bottom of the stroke. If the stroke is 4 in. and the connecting rod is

8 in. long, two of the piston pins are 6 in. above and two are 10 in. above the crankshaft center, the average distance being exactly 8 in. The view at the right shows the crank arms horizontal, with all four pistons near, but not exactly at, the middle of the stroke. The connecting rod forms the 8 in. hypotenuse of a right triangle, the horizontal side of which is 2 in. Computing the third side by difference of squares shows the vertical side to be approximately 7¾ in.

Therefore, the center of gravity of the four pistons, four piston pins, four sets of piston rings, and the upper end of each of the four connecting rods is about ¼ in. lower when the cranks are horizontal than when they are vertical. The total weight of these parts which must be moved up ¼ in. and down ¼ in. during each half revolution of the crankshaft may be more than 12 lb even for a small passenger car. Thus the vibration has a frequency of twice the engine speed. This is the cause of the vibration frequently found in four-cylinder engines at high speeds. Six-cylinder, twelve-cylinder, sixteen-cylinder, and in-line eight-cylinder engines are free from vibration of this particular sort.

Reference to Fig. 34 will help to explain the firing order of a four-cylinder engine. As No. 1 piston moves downward on power, No. 4 piston must move downward on suction; No. 2 piston can be moving upward on exhaust or compression and No. 3 will be moving upward on compression or exhaust. Table I of Fig. 33 shows the power balance with No. 2 piston on exhaust and No. 3 piston on compression. Table II shows the power balance resulting from No. 2 piston moving upward on compression and No. 3 on exhaust. With either arrangement the power impulses are evenly distributed, that is, they are 180 deg apart. Each arrangement gives a different firing order. That of Table I gives a firing order of 1–3–4–2 and that of Table II, a firing order of 1–2–4–3. American four-cylinder passenger cars have standardized on a firing order of 1–3–4–2.

Six-Cylinder Engines. — Six-cylinder engines are built with 120-deg crankshafts. The crankshaft is arranged so that the crank throws of cylinders Nos. 1 and 6, 2 and 5, and 3 and 4 are in the same radial plane as shown in Fig. 35. With this construction there will be six power impulses during two revolutions of the crankshaft. Because of this arrangement of the crankshaft with the proper firing order, as explained later, the six-cylinder engine, unlike the four-cylinder engine, has perfect inherent balance of both primary and secondary inertia forces.

By reference to Fig. 35 (upper left) it will be seen that, as Nos. 1 and 6 pistons are starting downward, Nos. 2 and 5 are completing

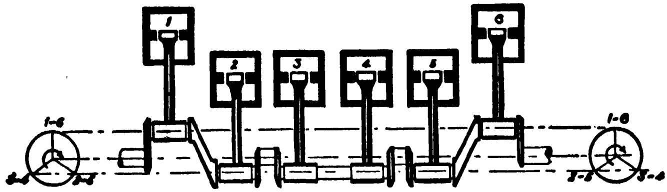


TABLE	I						II						III						IV					
CYLINDER	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
1st REVOLUTION	P	P	C	E	S	S	P	P	E	C	S	S	P	S	C	E	P	S	P	S	E	C	P	S
	P	E	C	E	C	S	P	E	E	C	C	S	P	C	C	E	E	S	P	C	E	C	E	S
	P	E	P	S	C	S	P	E	S	P	C	S	P	C	P	S	E	S	P	C	S	P	E	S
	E	E	P	S	C	C	E	E	S	P	C	C	E	C	P	S	E	C	E	C	S	P	E	C
	E	S	P	S	P	C	E	S	S	P	P	C	E	P	P	S	S	C	E	P	S	P	S	C
	E	S	E	C	P	C	E	S	C	E	P	C	E	P	E	C	S	C	E	P	C	E	S	C
2nd REVOLUTION	S	S	E	C	P	P	S	S	C	E	P	P	S	P	E	C	S	P	S	P	C	E	S	P
	S	C	E	C	E	P	S	C	C	E	E	P	S	E	E	C	C	P	S	E	C	E	C	P
	S	C	S	P	E	P	S	C	P	S	E	P	S	E	S	P	C	P	S	E	P	S	C	P
	C	C	S	P	E	E	C	C	P	S	E	E	C	E	S	P	C	E	C	E	P	S	C	E
	C	P	S	P	S	E	C	P	P	S	S	E	C	S	S	P	P	E	C	S	P	S	P	E
	C	P	C	E	S	E	C	P	E	C	S	E	C	S	C	E	P	E	C	S	E	C	P	E

TABLE	V						VI						VII						VIII					
CYLINDER	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
1st REVOLUTION	P	C	P	S	E	S	P	E	P	S	C	S	P	C	S	P	E	S	P	E	S	P	C	S
	P	C	E	C	E	S	P	E	E	C	C	S	P	C	C	E	E	S	P	E	C	E	C	S
	P	P	E	C	S	S	P	S	E	C	P	S	P	P	C	E	S	S	P	S	C	E	P	S
	E	P	E	C	S	C	E	S	E	C	P	C	E	P	C	E	S	C	E	S	C	E	P	C
	E	P	S	P	S	C	E	S	S	P	P	C	E	P	P	S	S	C	E	S	P	S	P	C
	E	E	S	P	C	C	E	C	S	P	E	C	E	E	P	S	C	C	E	C	P	S	E	C
2nd REVOLUTION	S	E	S	P	C	P	S	C	S	P	E	P	S	E	P	S	C	P	S	C	P	S	E	P
	S	E	C	E	C	P	S	C	C	E	E	P	S	E	E	C	C	P	S	C	E	C	E	P
	S	S	C	E	P	P	S	P	C	E	S	P	S	S	E	C	P	P	S	P	E	C	S	P
	C	S	C	E	P	E	C	P	C	E	S	E	C	S	E	C	P	E	C	P	E	C	S	E
	C	S	P	S	P	E	C	P	P	S	S	E	C	S	S	P	P	E	C	P	S	P	S	E
	C	C	P	S	E	E	C	E	P	S	C	E	C	C	S	P	E	E	C	E	S	P	C	E

Fig. 35 — Six-cylinder power-balance charts

their downward strokes, and pistons Nos. 3 and 4 are on their upward stroke. This is called a left-hand crankshaft. With this arrangement it is possible to have four different firing orders with events taking place as indicated in Tables I to IV inclusive. If the crankshaft arrangement is such that pistons Nos. 3 and 4 are finishing their downward stroke as pistons Nos. 1 and 6 are starting downward and Nos. 2 and 5 are on their upward strokes, as shown in the upper-right of Fig. 35, combinations of firing orders as indicated in Tables V to VIII inclusive of Fig. 35 are possible. This is called a "right-hand" crankshaft. With any of these combinations it is evident that the power impulses are evenly distributed and are 120 deg apart, the only difference being the order in which the cylinders fire. The eight possible firing orders are as follows:

Table I	— Firing Order — 1–3–5–6–4–2
Table II	— Firing Order — 1–4–5–6–3–2
Table III	— Firing Order — 1–3–2–6–4–5
Table IV	— Firing Order — 1–4–2–6–3–5
Table V	— Firing Order — 1–2–4–6–5–3
Table VI	— Firing Order — 1–5–4–6–2–3
Table VII	— Firing Order — 1–2–3–6–5–4
Table VIII	— Firing Order — 1–5–3–6–2–4

Of these eight possible firing orders, American six-cylinder passenger cars have standardized on 1–5–3–6–2–4 of Table VIII with the right-hand crankshaft arrangement as shown in the upper-right part of Fig. 35. When the left-hand crankshaft arrangement is employed, the 1–4–2–6–3–5 firing order usually is used.

Eight-Cylinder Engines. — Eight-cylinder engines are found in two types in passenger cars — the V-type and the vertical in-line "straight eight." The V-type is constructed by arranging two four-cylinder engines to operate from a single crank. The cylinders are set so that their centerlines form an angle (usually 90 deg as shown in Fig. 36) forming a V with the crankshaft as the junction point. As shown in Fig. 36, the connecting rods for the cylinders on the right operate on the same crankpins as the corresponding connecting rods on the left. It should be made clear, however, that these connecting rods operate independently of each other. Therefore, the operations of the cylinder shown at the right in Fig. 36 are always ahead of the cylinders on the left by the same number of degrees of crankshaft rotation as the angle of the V that the two banks of cylinders make with each other. Since the angle of the V is 90 deg in Fig. 36, when

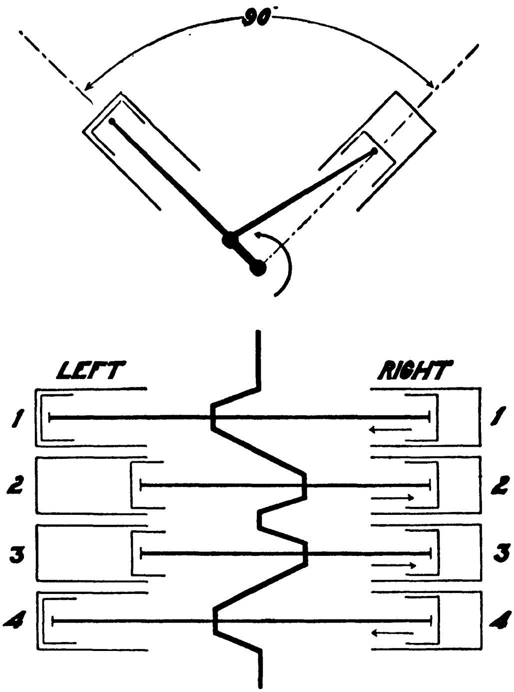


Fig. 36 — V-eight-cylinder power balance

No. 1 piston on the left is at top dead-center as shown, No. 1 on the right has completed half of its downward stroke. Although the primary inertia forces are balanced in V–8 engines, the secondary forces are out of balance and tend to induce a horizontal vibration which generally requires the use of a friction damper to neutralize it.

American V–8 passenger-car engines employ two methods of numbering the cylinders as shown in Fig. 37, each of which has its own firing order. The method of numbering shown at *A* is used on all Cadillac and LaSalle V–8 engines; a corresponding firing order of 1–8–7–3–6–5–4–2 is employed in these engines. The arrangement shown at *B* is used in Ford and Mercury V–8's with a corresponding firing order of 1–5–4–8–6–3–7–2. The firing order selected, of course, deter-

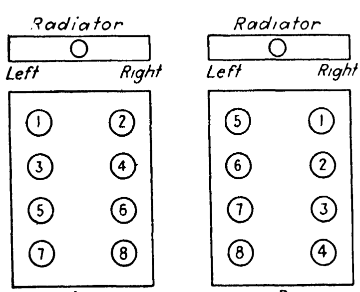


Fig. 37 — Methods of numbering cylinders in V–8 engines

mines the arrangement of the throws of the crankshaft and the cams of the camshaft.

Straight-eight engines which have their cylinders in line use a crankshaft with the throws set 90 deg from each other. The crank throws for cylinders Nos. 1 and 8 are in the same radial plane, as are the throws for cylinders 2 and 7, 3 and 6, and 4 and 5. The end views form a cross as shown in Fig. 38. As in all eight-cylinder

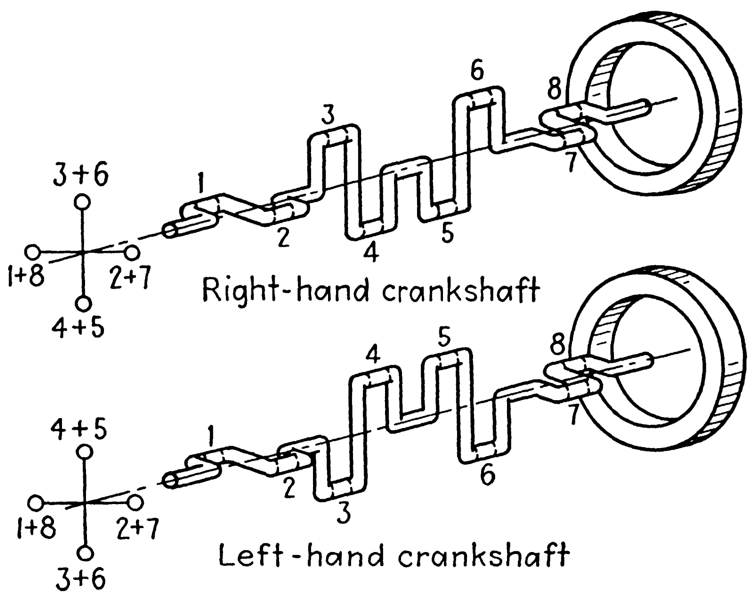


Fig. 38 — Typical eight-in-line crankshaft arrangements

engines, there is a power impulse for every 90 deg movement of the crankshaft. The standard firing order in American straight eights is 1–6–2–5–8–3–7–4. Cylinders are numbered consecutively from the radiator backward, as in all in-line engines. These engines are more compact in width than are V–8's; they also possess the advantage that the pistons do not bear on one side of the cylinder walls due to the angularity of the cylinders. Furthermore, the straight eight is inherently a perfectly balanced engine; both primary and secondary inertia forces are in balance.

Twelve-Cylinder Engines. — These engines consist essentially of two six-cylinder in-line engines, each forming a bank of the V with a common crankshaft and camshaft. For this reason V–12 engines are in perfect balance regardless of the angle of the V. In 1941 only one line of American passenger cars was equipped with V–12 en-

gines. The cylinders are numbered as shown in Fig. 39*A*, and their firing order corresponding to their numbering is 1–4–9–8–5–2–11–10–3–6–7–12. The angle of the V is 75 deg.

Sixteen-Cylinder Engines. — A straight-eight engine makes up each bank of this V-type engine. Consequently it is perfectly balanced. In the Cadillac sixteen-cylinder engine, discontinued in 1940, the cylinders are numbered as shown in Fig. 39*B* with a firing order of 1–4–9–12–3–16–11–8–15–14–7–6–13–2–5–10. With eight power impulses equally spaced for every revolution of the crankshaft, this engine gives virtually a continuous flow of power and very smooth operation. The angle of the V on this engine is 135 deg.

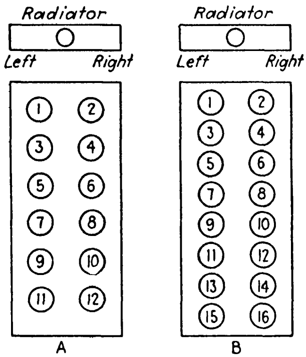


Fig. 39 — Methods of numbering cylinders in twelve-cylinder engines (*A*) and sixteen-cylinder engines (*B*)

Engine Balance and Firing Order Service. — When it is necessary to install one or more new pistons or connecting rods, great care must be taken that the weights of the new ones (within very close tolerances) are the same as the ones replaced. Otherwise, a vibration will be set up within the engine. When installing a complete new set of pistons and connecting rods, however, the weights of all the new units set may vary from the old set as a whole. In some V-type engines, nevertheless, the new set must weigh exactly as much as the original set, comparing piston to piston, or rod to rod. This is because the original engine was dynamically balanced with the connecting rod and pistons, and any excess in weight or decrease in weight will throw the engine out of balance and set up a vibration.

In most engines the flywheel can be mounted on the crankshaft in only one position. It is always safe, however, to put a punch mark on the inner circumference of the flywheel next to a punch mark on the crankshaft, so that there can be no mistake in putting the flywheel back exactly as it was originally. This is necessary for two reasons: (1) the timing marks on the flywheel must be kept in the same relative position to piston travel as originally, in order to check valve and ignition timing, and (2) the flywheel also has been balanced, and a change of position would affect the engine balance.

CHAPTER IX

ENGINE LUBRICATION

Lubrication is probably the most important phase of engine maintenance. Inadequate or improper lubrication can be the cause of a long line of serious engine troubles, such as scored cylinders, burned-out bearings, excessively worn bearings, misfiring cylinders, dirty spark plugs, stuck piston rings, engine deposits and sludge, and excessive fuel consumption.

Lubrication Systems. — A single system lubricates the entire engine of all present-day motor vehicles. (Only some equipment outside the engine, such as the starter, generator, water pump, and distributor is separately lubricated.) This system circulates oil from a common reservoir or sump in the bottom of the crankcase to the main bearings, connecting-rod bearings, wristpins, camshaft bearings and cams, cylinder walls, valves, and timing drive. In modern American automobiles this system is classified as " pressure " or " splash," although various combinations of these two systems have been used in the past. Most passenger cars use the pressure system in which the oil is forced under pressure by a geared pump to most of the various rotating or reciprocating parts.

The splash system utilizes dippers on the ends of the connecting rods to splash the oil on the various parts as they travel through oil troughs at the bottom of the stroke for distribution of the lubricant. A pump is employed to carry the oil to the troughs. Details of both these systems will be discussed later.

Lubricants and Lubrication Problems. — It is evident that the engine or crankcase oil must be suitable for the proper lubrication of a number of different parts, and hence must satisfy many requirements.

The lubricating oil in an automotive engine has five important functions: (1) to minimize friction and wear; (2) to cool by carrying away heat; (3) to seal the pistons and thus prevent the escape of gases in the cylinders with consequent loss of power; (4) to cushion the parts against vibration and impact; and (5) to clean the parts as it lubricates them, carrying away impurities.

Friction may be defined as a force which acts to resist or retard the rubbing motion. The magnitude of this retarding frictional

force depends upon the nature of the surfaces, the pressure which forces the surfaces together, and the kind of material used in the surfaces. Friction is low when the surfaces are smooth and highly polished, when the pressure is low, and when the material is hard. Conversely, rough surfaces, high pressures, and soft materials produce high frictional forces. Friction always produces wear and heat.

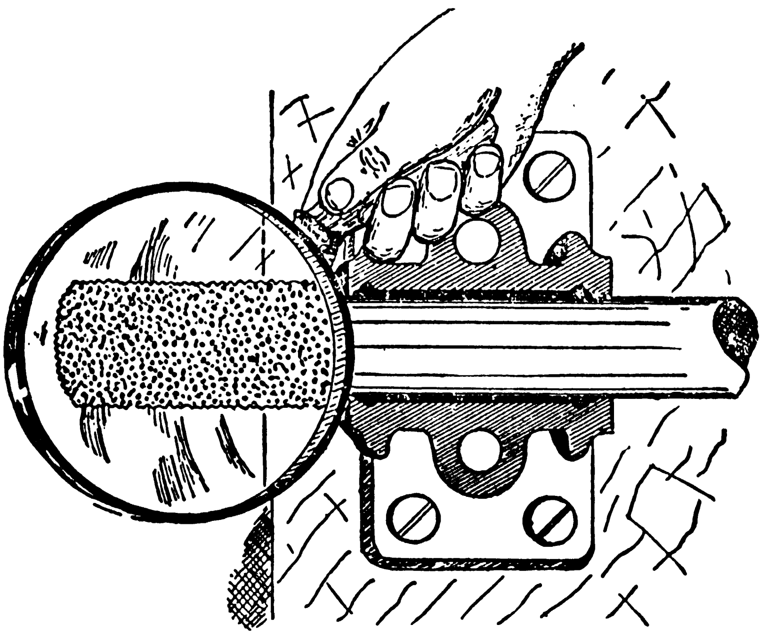


Fig. 40 — Magnified bearing surface of shaft journal

Whenever any two metal surfaces — such as a shaft in a bearing or a piston on a cylinder wall — rub against each other, there is friction between them no matter how highly polished the surfaces because the high points on one surface strike the high points on the other surface. Fig. 40 shows how these irregularities on the highly polished surface of a bearing journal show up when examined under a magnifying glass or microscope. If the journal and bearing lining were allowed to rub against each other without lubrication, there would be a loss of power, considerable wear, and the heat generated would cause the bearing to bind or "burn out."

The materials of automotive bearings are selected for the purpose of keeping friction to a minimum. It has been found that bearing linings made of certain soft materials give the least friction when

used with the steel shafts used in automobile engines and when lubricated properly. Most engines use bearing liners of " babbitt," an alloy of various combinations of tin, lead, zinc, and antimony, although some engines use cadmium-silver or copper-lead as explained in Chapter V.

In normal lubrication of engine bearings where the shaft " floats " on a film of lubricant, virtually all the friction takes place in the film of lubricant. The greasy slippery particles of the oil film slide or shear on each other, minimizing the amount of friction, wear, and generated heat. This action can be easily understood by likening it to that in a deck of cards when they are spread out on a table, the layers of lubricant in the oil film being displaced from each other by the rotating shaft in the same way that the cards overlap one another.

But, it is not enough to place the lubricating oil between the surfaces. A film of oil must be maintained in the bearings under practically all operating conditions. This means that an adequate amount must be fed continuously to the bearings.

Theory of Plain Bearing Lubrication. — How this film is maintained may be explained by reference to Fig. 41. It is seen that the journal takes an eccentric position in the bearing when in operation. This position is the result of the loading of the bearing *W* and the direction of rotation. The oil film is maintained by the wedging action as the oil is forced into the wedge at the bottom by the pressure generated when the oil is carried from the wide space *A* and forced into the narrow space *B* at the bottom by the rotating journal to which the oil adheres. This is called the " hydrodynamic " theory of lubrication. From this explanation it becomes evident that the oil film is maintained only when the journal is in motion, and the oil film is squeezed out from the pressure area *B* when the bearing comes to rest. When an automotive engine is first started, so-called " boundary lubrication " comes into play until the oil film is built up by the rotating journal as just described. The qualities of a lubricant called adhesiveness and film strength cause the lubricant to enter the metal pores and cling to the surfaces of the bearings,

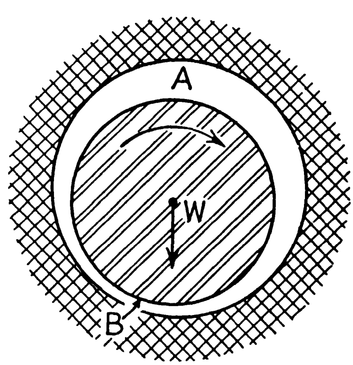


Fig. 41 — Position of rotating shaft, bearing lining, and film of lubricating oil

keeping them wet when the bearings are at rest and preventing metal-to-metal contact until the film of lubricant is built up. This property of " oiliness " also is highly desirable in helping the lubricant to adhere to the cylinder walls.

Load, speed, and body of the lubricant affect the thickness of the oil film in a bearing. The higher the load, the thinner the film; the higher the speed, the thicker the film; and the heavier the oil, the thicker the film. However, since a heavier oil increases the friction and raises the temperature, the higher temperature will thin the oil and thus reduce the friction again. Therefore, use of a heavier oil often results only in raising the temperature of the bearings. For these reasons oil companies recommend the use of the lightest oil in automotive engine bearings which can be depended upon to maintain an oil film of satisfactory thickness, and which has sufficient adhesiveness and film strength to provide satisfactory " boundary lubrication " when the engine is starting from rest, and to adhere satisfactorily to the cylinder walls.

More oil is circulated through the bearings of automotive engines than is necessary for lubrication purposes alone. This permits the oil to perform properly the second function mentioned previously — to cool by carrying away heat. The hot oil leaving the bearings is carried to a central point where it is cooled before being recirculated to the bearings.

Cylinder Lubrication. — In both the pressure and splash systems the cylinder oil is thrown to the lower end of the cylinder by the rotation of the crankshaft and connecting rod, and spread over the cylinder walls by the up-and-down motion of the piston. This oil must withstand severe conditions of high temperatures and pressures, and must have sufficient oiliness, film strength, or adhesiveness to cling to the cylinder walls and maintain " boundary lubrication." These conditions impose severe requirements on the properties of the crankcase oil.

Types of Lubricants. — Lubricants are classified in three forms — fluid, semi-solid, and solid. Fluid oils are used in automobile engine lubricating systems. Semi-solid oils are used in rear-axle lubrication. Solid lubricants are such as graphite and mica. Graphite often is mixed with oil to lubricate automobile springs. The use of these types depends upon the work required and the surfaces to be lubricated.

Lubricants also are classified according to their source — as animal, vegetable, or mineral. Animal oils are obtained from such sources as lard and fish. Olive oil, castor oil, and linseed oil are

typical vegetable oils. Mineral oils are obtained by distillation from petroleum.

Mineral oils are used almost entirely for lubricating automotive engines because they have most of the qualities desired and are cheaper and more plentiful than the other types. They are obtained by distillation from petroleum. They are free from acid when properly refined and therefore do not attack the metals or cause chemical reactions.

Often small amounts of animal or vegetable oil or other material are mixed with a lubricating oil to obtain some desirable quality not provided by the pure oil. This practice, called "compounding," is frequently employed in oils used in diesel engines, the purpose being to give a solvent or cleaning property that dissolves impurities and eliminates stuck piston rings. Such " additives " also are used to increase the " oiliness " of cylinder oils, to thicken the oil, and so on.

Mineral oils have a third classification — according to the crude oil from which they are distilled. When the residue remaining after distillation is largely paraffin, they are termed " paraffin-base " oils. Most of the crude oils from which paraffin-base oils are distilled come from fields in the Eastern part of this country, and include the so-called Pennsylvania oils. " Naphthene-base " oils have a residue containing quantities of asphaltum, and usually come from oil fields of California, the Gulf Coast, and Mexico. Some oils consist of a blend of these two types. Lubricating oils also are blended of oils of different characteristics to obtain a desired result. Paraffin-base oils weigh less than naphthenic-base oils and have less tendency to thin out at high temperatures. Naphthene-base oils are more volatile and congeal at lower temperatures than do paraffin-base oils. However, these inherent characteristics may be modified considerably by treatments and refining processes.

Tests and Ratings. — Lubricants are tested and rated in accordance with certain tests:

Viscosity. — This is one of the most important properties of an oil, and is used universally to grade lubricants. Viscosity is a measure of the resistance to flow or of the internal friction of an oil. Essentially it means " body " — a heavy oil having high viscosity and a light oil, low viscosity. The viscosity of an oil usually is specified at the time in seconds that it takes for a given amount of the oil to flow by gravity through a standard-sized orifice or hole at a given temperature. In the Saybolt Universal system universally used in this country, the hole is 0.1765 cm in diameter, the quantity of oil is 60 cc, and the temperature usually is 100, 130, or 210° F,

depending upon whether the oil is to be tested is light, heavy, or medium.

A very important characteristic of mineral oils is that the viscosity decreases as the temperature rises, and increases as it falls. This explains why lighter oils are recommended for automobile engines in winter than in summer, and why engines are so hard to start in very cold weather. This is the reason also why oils are tested for viscosity at a specified temperature.

Furthermore, all oils do not thin out or become less viscous at the same rate as the temperature rises. To take account of this factor, another means of rating oils called " viscosity index " is employed. In its use every lubricant is given a number to indicate the rate at which it thins out as temperatures rise, or at which it gets heavier as temperatures fall. The rate of change of viscosity between two temperatures, 100 and 210° F, is used as a basis for this value. The lower the rate of change, the higher the viscosity index. Pennsylvania oils have an average viscosity index of 100; values for most other oils are lower.

In practice lubricating oils usually are marketed by their SAE viscosity numbers, recommended by the Society of Automotive Engineers. The viscosity number of any crankcase lubricating oil is determined by the range of viscosities within which it falls at the given temperature. The following recommendations appeared in the SAE 1941 Handbook and are susceptible to revision at later dates:

S. A. E. Viscosity Number	Viscosity Range, Saybolt Universal Seconds			
	At 130 Deg. Fahr.		At 210 Deg. Fahr.	
	Min.	Max.	Min.	Max.
10	90	Less than 120	......	....
20	120	Less than 185	.. ...	.. ..
30	185	Less than 255	. ....	....
40	255	....	. .	Less than 80
50	......	....	80	Less than 105
60	......	....	105	Less than 125
70	......	....	125	Less than 150

Every motor-vehicle manufacturer specifies certain SAE viscosities for use when operating in certain temperature ranges. In general, these recommendations range from SAE 10 to SAE 40 for operation in the coldest to hottest atmospheric temperatures. Specifically these recommendations cover four temperature ranges: lowest expected temperature —10° F; lowest expected temperature

10° F; lowest expected temperature 32° F; and temperatures above 90° F.

In recent years the trend has been toward lighter engine lubricants, many manufacturers specifying SAE 10 and 20 for the entire range of operating temperatures below 90° F. Use of these lighter lubricants has been made possible by smaller bearing clearances and closer piston fits resulting from the more accurate and smoother surfaces obtained by modern production finishing operations. Some oil companies employ the designation "W" (meaning "winter") after the SAE viscosity number to denote that the viscosity of the oil will be low enough at 0° F for satisfactory starting under severe winter temperatures.

Specific Gravity. — This property is a measure of the density or unit weight of an oil. In general practice it is determined by a hydrometer which floats in the oil, and the gravity is read on the scale of the hydrometer at the surface of the oil. The scale used is the one recommended by the American Petroleum Institute, and the result is called the "API gravity."

Flash Point and Fire Point. — The flash point is defined as the lowest temperature at which lubricating oil will "flash" when a lighted taper is passed across its surface. If the oil is heated further after the flash point has been reached, the lowest temperature at which the oil will burn continuously is called the fire point. These two temperatures must be high enough in a lubricating oil so that the oil does not flash or burn in service. The flash point is the only one used commercially.

Pour Point. — This property is defined as the lowest temperature at which a lubricant will pour. This characteristic must be taken into consideration because of its effect on starting an engine in cold weather and on free circulation of oil through exterior feed pipes when pressure is not applied. Oils for automobile use in the northern sections of the country, of course, would need to have lower pour points than those used in the South.

Other tests are for carbon residue, as an indication of the carbon-forming tendencies of the oil; for acid by means of litmus paper; for color, as denoted by NPA numbers (National Petroleum Association); for emulsification, as measure of its tendency to mix with water; for oxidation; and for corrosion. In making these tests the specifications recommended by the American Society for Testing Materials generally are followed.

Engine Lubricating Systems. — As explained in the introduction of this chapter, automobile lubricating systems are of the pressure or

splash type. Pressure systems are of two types — the full pressure system in which the oil is supplied by pressure to the wristpins or piston pins through holes drilled in the connecting rods and the partial pressure system which does not have this feature and lubricates the wristpins by splash. These pressure systems have replaced the splash system of lubrication until, in 1941, only one line of American passenger cars was using the splash system. An important advantage of the pressure system over the splash system is the greater cooling effect obtained by the faster circulation of oil.

Full Pressure System. — In this system, shown in Fig. 42, oil is supplied under a normal pressure of from 25 to 45 lb per sq in. from

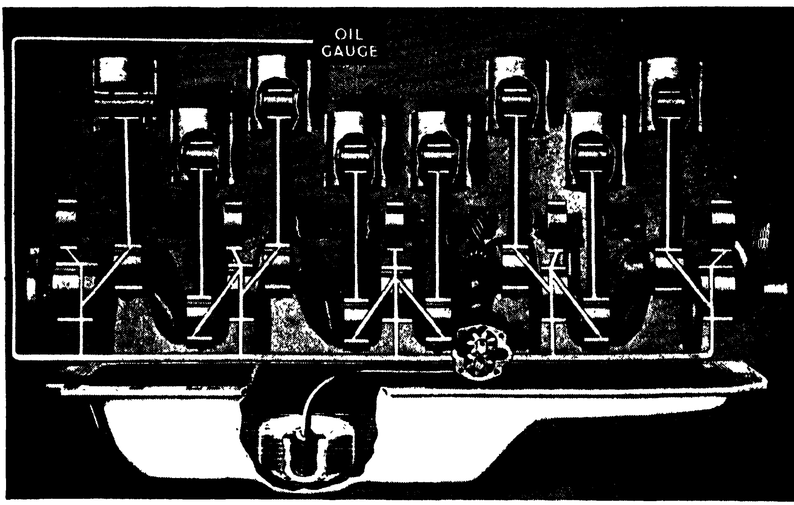


Fig. 42 — Full pressure system of lubrication

the geared pump shown, directly to the main bearings. From the main bearings it is forced through holes drilled in the crankshaft to the connecting-rod bearings. From the connecting-rod bearings the lubricant is forced through holes drilled in the connecting rods to the wristpins. Leads from the main bearings, as shown, deliver oil under pressure from the main bearings to the camshaft bearings. In some designs the oil from one of the camshaft bearings goes through the oil filter. An oil jet is employed to lubricate the timing chain. Even in the full pressure system, the oil from the ends of the connecting-rod bearings is thrown up to lubricate the cylinder walls and cams. In this system, as in all systems, the oil is thrown to the lower part of the cylinder walls where it is spread over the cylinder walls by the reciprocating pistons. The oil rings on the

piston control this distribution, carrying the oil upward to the cylinder walls and wiping and draining off excess oil. Excess oil escaping from bearing ends and falling from pistons, cylinders, and so on, of course, is returned to the oil sump for recirculation.

Partial Pressure System. — This system is virtually the same as the full pressure system except that the wristpins are lubricated by the oil which is thrown up to the wristpins by the motion of the crankshaft and connecting rods. Oil is forced under a normal oil pressure of from 15 to 75 lb per sq in. to the main and connecting-rod bearings by a geared oil pump. Camshaft bearings receive pressure lubrication from the main bearings as in the full pressure system. Overflow oil from the connecting-rod bearings is thrown by centrifugal force to the cylinder walls, piston walls, wristpins, and cams. The overflow of the oil returns to the sump and is recirculated.

Pressure Gages and Pressure Relief Valves. — An oil pressure gage is mounted on the instrument panel of all cars provided with pressure engine lubrication. The gage piping is connected to the main engine supply line.

Since the pressure in the engine lubricating system depends upon the speed at which the gear-type oil pump is driven, some means must be provided to keep the pressure from rising above desired values at high engine speeds. A pressure relief valve is included in every pressure system for this purpose. When the pressure rises above the value for which the spring in such a valve is set, the spring is compressed, opening the valve and permitting some of the oil to return to the sump, thus reducing the pressure. These valves often are placed in a bypass passage between the delivery and suction side of the oil pump.

Splash System. — This system is so named because virtually all parts are lubricated by the oil splashed from the ends of the connecting rods by centrifugal force as they dip into oil troughs at the bottom of their stroke, as shown in Fig. 43. The splashing action creates a mist which reaches all parts to be lubricated. The ends of the connecting rods are provided with extensions or dippers which are hollowed out to catch the oil. As shown, the oil is pumped from the sump to small troughs under each connecting rod. Each trough is provided with an overflow which keeps the supply in each trough at the same level since an excess of oil is supplied. By this method oil is splashed to all engine parts to be lubricated — including main bearings, camshaft bearings, cylinder walls, pistons, wristpins, valves, timing gear, and cams. Oil is forced to the connecting-rod

bearings by centrifugal force through holes drilled in the connecting-rod bearing caps, as shown in Fig. 43. Pockets are provided above the various bearings to catch the splashing oil and deliver it by gravity to the bearings below. In some designs oil is pumped di-

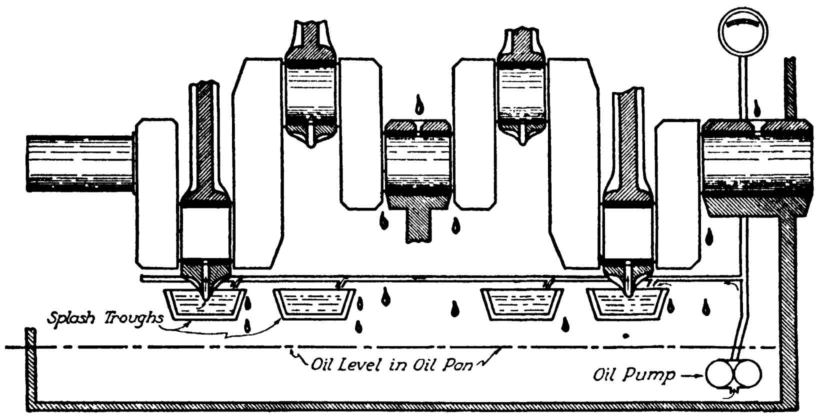


Fig. 43 — Circulating splash lubricating system

rectly to openings in the top of the main bearings. Overflow oil is returned to the sump by gravity for recirculation.

Oil Pumps. — The geared oil pump shown in Fig. 44 is used to supply oil under pressure to all pressure or force-feed systems in American passenger cars. It consists essentially of two meshed spur gears enclosed in a tight-fitting housing. One gear is attached to a shaft through which it is driven through suitable gearing from the camshaft or crankshaft of the engine. The other gear is free to revolve or idle on its own bearings. The oil is drawn between the teeth of the gears from the inlet side, carried around between the gears and the pump housing, and forced out the outlet side, the meshing of the gear teeth in the center preventing the passage of oil between the teeth in this location. It is apparent that, the higher the speed of the gears, the more oil is pumped and the greater the pressure in the system.

The reciprocating plunger type of pump is employed to deliver oil under low pressure to the troughs of splash systems. It is very much like an ordinary bicycle pump and is driven by gears from the camshaft with an eccentric cam to reciprocate the pump plunger. The plunger draws oil into the cylinder and forces it out to the parts requiring lubrication through the action of ball valves. As in the case of the gear pump, the faster the engine revolves, the greater the amount of oil delivered by the pump.

Oil-Level Gages. — The amount of oil in the crankcase of an engine is determined in most cars by means of a " splash stick," a long flat rod which dips into the oil through a tube at the side of the crankcase. When the rod is pulled out, the oil level of the crankcase is indicated by the topmost position of the oil adhering to the rod with reference to marks on the rod corresponding to various crankcase levels. The reading should be taken when the engine is

Fig. 44 — Gear-type oil pump

not running and the car is in a level position. The rod should be withdrawn, wiped clean, and re-inserted before making a reading.

The oil level in the crankcase in some cars is indicated by a float gage. It consists of a cork or hollow metal float, which is supported on the surface of the oil reservoir, the position of the float being indicated on a gage dial through suitable connecting linkage.

Oil Filters. — Although screens or strainers are provided at the intake opening of the oil pump and at the oil-filler opening to prevent the entrance of dirt and foreign matter to the oil system, separate oil filters are placed in the engine lubricating systems of many motor vehicles. Through these filters all or part of the oil in the system passes and small particles of dirt or grit that enter or are formed in the system are removed. For example, in some designs of full pressure systems, only the oil going through one camshaft bear-

ing is filtered. In most installations the oil can be bypassed around the filter when the latter becomes filled with dirt. These filters are of several designs. One type consists of a sealed metal container with a cloth filter element through which the oil is passed. The foreign material is collected and held in the cloth element, only the clean oil passing through. In other types the oil is forced through fine-mesh metal or metal ribbons wound in the form of a helix. Filter manufacturers recommend that filter elements be renewed at from 8000 to 10,000 miles of operation in clean operating conditions, these periods to be reduced accordingly in dusty or dirty operating conditions. Some types of filters do not require renewal, but merely periodic cleaning. Oil filters are furnished as standard equipment on many cars, and are optional on the remainder.

Oil Breather. — An opening of the engine lubrication system to the outside air is necessary to prevent excess pressure from building up in the lubricating system and to provide an inlet for crankcase ventilation. This opening is called a " breather " and usually is combined with the oil filler tube. To prevent air leaving the crankcase from taking oil with it, baffles are provided in the breather tube. An air cleaner or strainer often is supplied at the breather mouth to prevent the entrance of dirt into the crankcase.

Crankcase Ventilation. — Dilution of the lubricating oil in the engine crankcase with water and gasoline is likely to occur unless some means is provided to prevent it. The water may be condensed from water vapor in the crankcase air when the engine is stopped and the crankcase allowed to cool. Much of this water vapor may be a byproduct of combustion in the cylinders that has leaked through the piston rings into the crankcase. The gasoline also finds its way into the crankcase oil by slipping past the piston rings in the form of " blowby," particularly when the carburetor is being " choked " to assist cold-weather starting. If either the fuel or oil contains sulfur, sulfuric acid may be formed by such dilution. This acid causes corrosion of the crankcase metals as does water if either or both are allowed to collect and remain in the crankcase.

Crankcase ventilation is employed in many automotive engines to minimize this dilution. This ventilation consists in passing through the crankcase a constant stream of air which picks up and carries away most of the fuel vapor and water vapor before they can condense out and dilute the oil.

Air is drawn into the crankcase through the breather and is discharged through an outlet near the rear of the cylinder block. The suction developed by the moving pistons, the fanning action of the

rotating crankshaft, and/or the forward motion of the car are utilized to circulate the air through the crankcase.

Oil Coolers. — Since one of the most important functions of the engine lubricating oil is to cool the bearings and other rubbing parts, any device which will keep the oil as cool as possible will add to the efficiency of lubrication. Partly for this reason oil coolers are included in the engine lubricating systems of some passenger cars.

Oil coolers are essentially small radiators mounted on the side of the engine. Water from the main engine cooling system is circulated through the tubes in one design, and the oil flows around these tubes. It is evident that these " oil coolers " actually will heat the oil during starting as the water heats up faster than the oil, and will not cool the oil until the oil temperature tends to become higher than that of the water, as occurs during high-speed operation. For this reason these devices are more correctly termed " oil regulators " by some manufacturers. By keeping the oil temperature within a narrower range, it is obvious that friction is lessened and efficiency increased.

Equipment Not Lubricated by Engine System. — Separate means are provided for lubricating the water pump and fan, starter and generator, and distributors. The types of bearings and lubrication recommended for water pumps and fans vary widely. Sealed ball bearings packed in grease, and porous bronze plain bearings lubricated by grease cups containing special water-pump grease are two of the methods commonly used. Generators usually are provided with ball bearings on the drive end which require lubrication with a few drops of light oils at regular but infrequent intervals. Babbitt or bronze bearings lubricated from grease cups sometimes are employed on the commutator end of the generator. Starting motors, being used for short periods only, usually are fitted with babbitt, bronze, or " oilless " bearings. Usually the upper shaft bearing of the distributor requires separate lubrication. The construction of this bearing and the lubrication recommended vary widely among different motor cars.

Repairing Engine Lubrication Systems. — Failure can occur in only two ways in engine lubricating systems — in the pump itself, which seldom gives trouble, and in the oil lines leading to and from the pump.

If it is suspected that the pump is out of order, it should be removed and tested by turning the pump shaft by hand with the inlet line in oil and noticing whether oil comes from the outlet line. In time the oil pump gears or plunger may wear, necessitating over-

haul of the pump. The pump is removed from the engine as a unit. The spur gears inside the pump may be pressed from their shafts and replaced with new ones if necessary. When the pump is disassembled, all the parts should be cleaned thoroughly in gasoline. The intake screen, which collects sludge and particles of dirt and grit held in suspension in the oil, also should be cleaned. In reassembling, care should be taken that the drive gear is pressed on the correct distance given in the factory specifications so that there will be the proper amount of end play to the pump shaft.

If the pump is found to be in good condition but the oil still does not get to the bearings, blow out with compressed air all oil lines that can be removed from the engine. If it is found that these lines are not clogged, it will be necessary to remove the engine from the car, take it apart, and clean all the oil passages in the crankshaft, connecting rods and cylinder block. This last procedure, of course, would be followed naturally since, if the oil lines are clogged, the bearings probably would have been damaged or burned for lack of oil, and the engine would be removed to do a thorough job.

If the oil gage on the instrument panel shows that the pressure is too low, the car should not be run until the trouble is located. It may be that there is not enough oil in the oil pan, or that there is a loose connection in the oil line supplying the pump, or in the discharge line. Low oil pressure also may be a sign of excessive clearance in the bearings, causing rapid oil leakage from the bearing ends and, as suggested in Chapter VI, a test for leaky bearings can be made with a pressure oil leak detector.

Oil pressure that is too low or too high also can be caused by the relief valve spring being too weak or too strong. On some cars a method is provided for lessening or strengthening the spring pressure to bring the oil pressure to factory specifications. On most cars, however, a new spring must be installed to produce the correct pressure. Shims or gaskets, added to or removed from the relief valve spring retainer, are employed to correct the pressure in other systems.

In addition to loose main or connecting-rod bearings, high oil consumption may be due to: tapered or out-of-round cylinders; worn piston rings; worn oil seals at front or rear main bearings; a clogged oil return pipe at rear main bearing; a worn rear camshaft oil seal; a clogged oil breather; clogged oil return from the distributor; leaky fuel pump vacuum booster diaphragm which sucks oil from the crankcase through to the intake manifold; excessive clearance in the intake valve guides; broken or improperly installed oil pan, valve

cover, or timing-gear cover gaskets; loose connections in oil-filter lines; excessive oil pressure; and cylinder distortion due to improper tightening of the cylinder-head nuts.

Care must be taken in replacing oil pumps that are driven by the same shaft through which the ignition distributor is driven. Since the drive gear for both units is on the oil pump, it is necessary to re-time the ignition when replacing such pumps.

The period between oil changes depends to a great extent on the type of roads and territory where most of the driving is done, and on the amount of driving done at one time. A car that is not driven much and does not get a chance to " warm up " should have the oil changed oftener than one that is warmed up and driven continuously for long periods. Water that is formed as a byproduct of engine combustion or condensation of water vapors in the crankcase will collect in the oil pan unless it is vaporized and carried away by the crankcase ventilation. This water tends to rust the engine parts and should be drained off with the oil. Dusty roads will fill the oil through the breather with particles that get in the bearings and cylinder walls and act as an abrasive unless removed by air filters or oil filters. Before draining the oil, the engine should be warmed up so that the oil will flow out the drain plug more easily.

CHAPTER X

THE COOLING SYSTEM

As previously shown, the internal-combustion engine is a machine for transforming heat into mechanical energy. Unfortunately, only about 25% of the heat generated can be so transformed, and about 35% of the heat wasted must be absorbed by the cooling water. As the heat increases, a greater expansion of the gases results and more power is developed. But there are limitations to the degree of heat that can be maintained in the engine without serious harm to its functioning. Too intense heat can cause the lubricant to be burned up, with a resulting scoring of cylinders, binding of pistons and bearings, warping of valves or any one of a variety of other mechanical troubles. So, a cooling system is needed to keep the engine from getting so hot as to cause these difficulties and yet permit it to run hot enough to insure maximum efficiency of operation. The duty of a cooling system, in other words, is to keep the engine from getting too hot — not to keep it cool. Most passenger-car engines operate best when the water leaving the water jacket is 180 to 200° F, but well under the boiling point.

In the cooling system of all American passenger cars, the water is circulated through jackets around each of the combustion chambers, cylinders, valve seats, and valve stems, and is kept in motion by a centrifugal pump which is driven by a V-belt from a pulley on the engine crankshaft. After passing through the engine jackets, the water is passed through the radiator where it is cooled by air drawn through the radiator by a fan and by the air flow developed by the forward motion of the car. Often the fan and pump are mounted and driven on a common shaft. After passing through the radiator, it passes out through a radiator outlet hose, back through the water pump and through a cylinder inlet hose back through the engine jackets again.

Bypass Recirculation. — Most modern cooling systems embody a thermostatic device which prevents the water in the engine jackets from circulating through the radiator for cooling until its temperature has reached a height suitable for efficient engine operation. The location and detailed functioning of these devices vary with different designs, but the principle of operation is the same in each case.

Fig. 45 illustrates the water circulation in a typical thermostatically controlled bypass system. Fig. 46 shows schematically the flow of water during recirculation and normal circulation. In this system, when the engine is first started and is cold, the valve operated by the thermostat is held tightly closed. This prevents the water pump from drawing water from the radiator. Then the water circulates from the pump through the cylinder block to the thermostat,

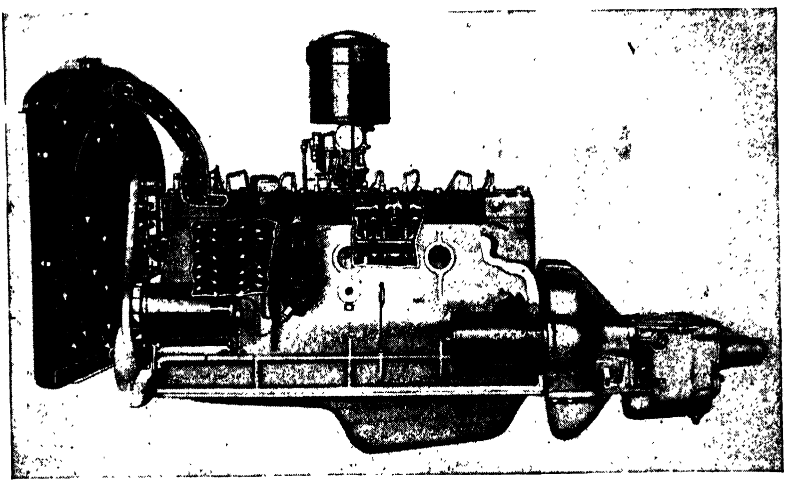


Fig. 45 — Water circulation in typical thermostatically controlled bypass cooling system

through the water bypass shown to the water inlet passage and back to the pump.

As the engine becomes heated and the small amount of circulated water becomes warm, it causes the thermostat to function, causing the valve to the radiator to open. Then the water circulates through the whole system as previously described. The amount of water circulated through the radiator depends upon the temperature of the water, which governs how far the thermostat opens the valve. The thermostat is set to start to open the valve admitting water to the radiator at a certain temperature (usually about 155° F). At a predetermined higher temperature (about 173° F) the valve is fully open. The thermostat consists essentially of a metal bellows containing a temperature-sensitive liquid which expands the bellows as heat is applied by the jacket water and contracts the bellows as the water cools.

The bypass is closed off from the remainder of the system when the hot water is flowing through the radiator by means of a spring-

loaded poppet valve. When the thermostat holds the valve leading to the radiator in a closed position, the pressure in the passage leading to the bypass increases, overcoming the valve spring pressure and opening the bypass valve automatically. When the thermostat opens the valve leading to the radiator, the pressure in the bypass is relieved and the spring closes the bypass valve automatically. The arrangement and operation of these valves are shown in Fig. 46.

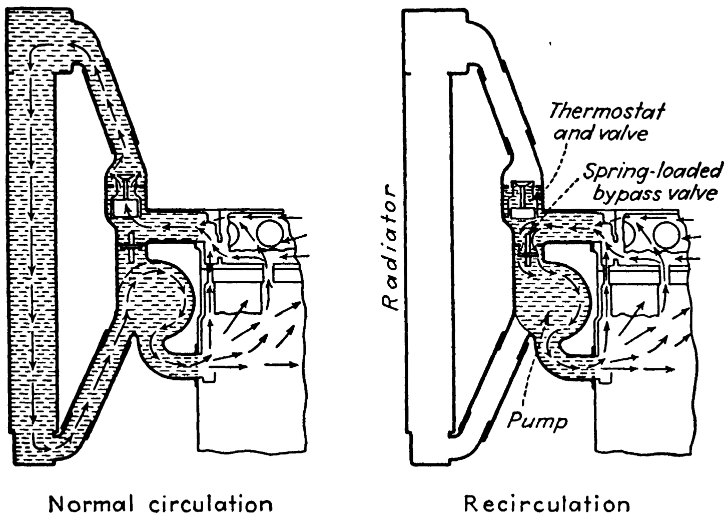


Fig. 46 — Water flow during recirculation through bypass and normal circulation

Automatic Radiator Shutters. — Instead of keeping the water from circulating through the radiator for quick warm-up and cold-weather operation, the cooling systems of some cars employ thermostatically controlled radiator shutters that shut off the cooling air from the radiator when the jacket water is below a predetermined temperature. The thermostat often is built into the top of the radiator as shown in Fig. 47 and operates the shutters through the linkage indicated. These shutters assume a closed position when the engine is cold. When the jacket water reaches the temperature for which the thermostat is set, the thermostat starts to open the shutters. Like the bypass recirculation system, the purpose of automatic shutters is to keep the cooling water as close to a constant efficient temperature as is practicable.

Closed Systems. — When a cooling system is open to the atmosphere, the temperature of its cooling water is limited by its boiling point (212° F) or lower if the coolant contains anti-freeze materials

that lower the boiling point of the mixture. In some systems the boiling point of the coolant is raised by keeping it under pressure in a closed cooling system. To prevent pressure in the system from becoming excessive and causing leaks in the system, pressure relief valves are used to open the system to the atmosphere whenever the pressure in the system exceeds a predetermined value. In the cooling

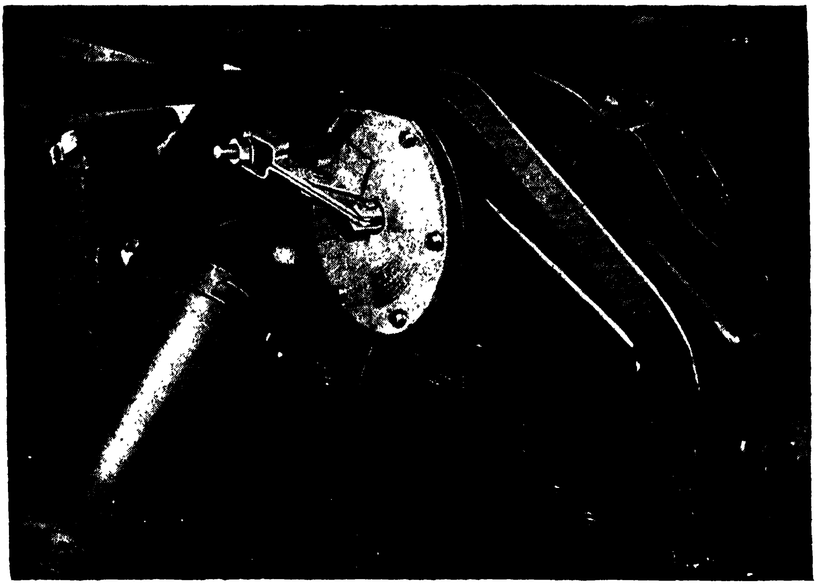


Fig. 47 — Thermostat arranged for controlling radiator shutters

systems of one line of cars, the relief valve is incorporated in a tight-fitting radiator filler cap. This relief valve is set to relieve any pressure in the cooling system above 7 lb per sq in. When the pressure in the cooling system is 3.5 lb per sq in., the boiling point of the water is raised to 225° F.

Advantages claimed for the closed pressure system are that, by raising the boiling point of the coolant, the cooling capacity of the system is raised; there is less likelihood of boiling over; and fuel vaporization and distribution are improved.

Water Pump. — Commonly used is a centrifugal type of pump in which the water entering the pump at the center is caught by rotating vanes and is thrown to the outside by centrifugal force (Fig. 48). The casing limits its outward motion, but allows the blades to impel it in circular motion, the pressure against the casing increasing until the outlet pipe is reached. Here the resistance to

its outward motion is removed and the stored-up energy forces the water through the discharge pipe to the water jackets. The rotating member, called the "impeller," consists essentially of a disc on which vanes or paddles are attached.

The pump either is driven from the fan belt or is mounted on a common shaft with the fan. Because of the clearance between the impeller blades and the casing, centrifugal pumps are non-positive in action and will not build up dangerous pressures if an obstruction should occur in the radiator or other part of the system, as would, for example, a positive geared pump.

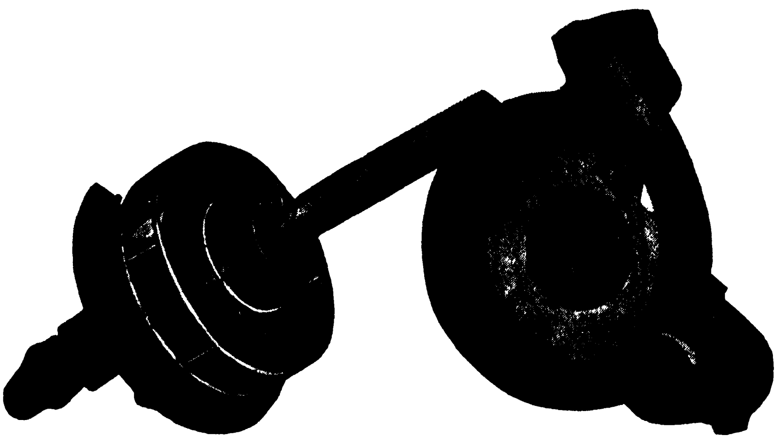


Fig. 48 — Centrifugal water pump

Radiators. — The purpose of a radiator is to present a large amount of cooling surface to the air so that the water passing downward through it in thin streams is cooled efficiently. To accomplish this, there are many constructions varying in design, partly in accordance with the ideas of different engineers and partly in accordance with the limitations imposed on radiator areas by modern automobile body design.

The radiator consists essentially of an upper tank containing the filler tank and a lower tank. Between these is the " core " or radiating element. The upper tank is connected to the water outlet or outlets from the engine jacket by rubber hose, and the lower tank is connected by hose to the jacket inlet through the pump.

All radiator cores may be classed as either tubular or cellular.

A tubular radiator is one in which the upper and lower tanks are connected by a series of tubes through which water must pass. In modern cars, these tubes are vertical, although zigzag patterns were

also used formerly. Typical tubular constructions are shown in Fig. 49.

A cellular radiator is composed of a large number of individual air cells which are surrounded by water (Fig. 49), the course of the water through the radiator not being confined to any definite vertical or angular course. Because of its appearance the cellular type usu-

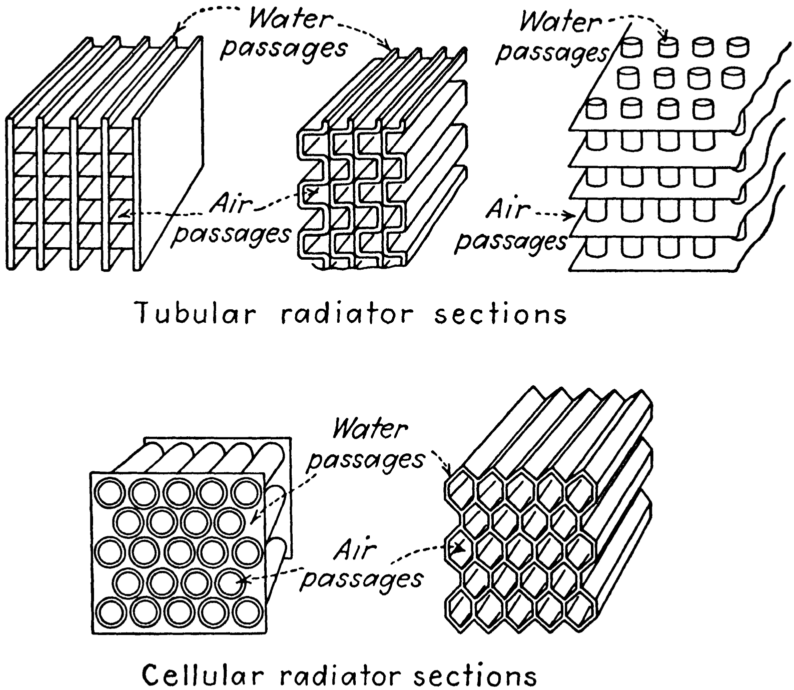


Fig. 49 — Types of radiator cores

ally is known as a " honeycomb " radiator, especially when the cells in front are hexagonal in form.

Since the water passes through all the tubes of a tubular radiator, if one tube becomes clogged, the cooling effect of the entire tube is lost. In the cellular construction, the clogging of any passage results in a loss of but a small part of the total cooling surface.

Fans. — As already indicated, the purpose of the fan is to draw air through the radiator with which to cool the water, supplementing the forward motion of the car. Fans are driven by belts made of a rubber composition and are called " V-belts " because of their V-shaped cross-section. The fan bracket is so constructed that the tension on the belt is adjustable. At all times the belt should be under sufficient tension to prevent slippage. Fans require but little

power and usually run at a speed greater than that of the crankshaft. Fans usually have four blades. Frequently the blades are spaced unequally around their spiders to promote quieter operation. They are mounted on ball bearings to reduce friction as much as possible.

Other Cooling System Types. — Two types of cooling systems no longer used in American passenger car practice are the thermo-syphon type and air-cooling. In the thermo-syphon type, the water entered the cylinder jacket at the inlet connection and, upon becoming heated by the combustion within the engine, expanded and rose to the top tank of the radiator from whence it entered the radiator core. As the water was cooled, it became heavier and therefore sank to the bottom of the cooling system ready for recirculation, replacing the hot water leaving the upper part of the jacket.

Air-cooling, which has found widespread use in airplane engines — where the conditions of operation are very different from those encountered in passenger car work — had its widest use in America in the Franklin car which is no longer manufactured. Since cooling by air depends upon the amount of surface presented to the air, the effective outer surfaces of the cylinders were increased by the addition of fins or flanges. In the Franklin, integral cooling fins were placed on both cylinders and heads. An air duct on the left side of the engine blew air across through the fins to the right side, the duct tapering from front to rear so that an equal supply of air was sent to all cylinders, without using baffles.

Anti-Freeze Mixtures. — There is little chance of the pump-circulated water in the cooling system of a modern car freezing while the car is in operation, but there is every chance of such freezing when the car is parked in unheated areas when temperatures are below freezing. When this occurs, the expansion may cause the water jackets, pipes or radiator to break.

To prevent freezing, various mixtures are added to the water in the winter to lower beyond the danger point the freezing temperature of the liquid in the cooling system. The ideal requirements for an anti-freeze mixture are:

1. It should cause no harmful effect to any part of the cooling system with which it comes in contact.
2. It should be easily dissolved in or combine with water.
3. It should be reasonably cheap.
4. It should not waste by vaporization; that is, its boiling point should be as high as that of water.
5. It should not deposit any foreign matter in the jackets or pipes.

The materials commonly used are wood alcohol, denatured alcohol, glycerine, ethylene glycol, mixtures of alcohol and glycerine, and various mixtures of other chemicals. Each type has some advantages and disadvantages. Alcohol, being more volatile and having a lower boiling point than water, evaporates, making constant additions necessary. For this reason, alcohol mixtures should be checked frequently with a suitable hydrometer. Glycerine has some tendency to attack rubber hose connections slightly unless the inside of the hose is shellacked. Ethylene glycol and glycerine are relatively high in price per quart, but do not evaporate and hence may prove cheaper in the long run if loss through leakage does not occur.

Servicing the Cooling System. — Service of the cooling system can be divided into three units: (1) the water pump; (2) the fan and fan belt; and (3) the radiator, hose connections, water jackets in the cylinder block, and thermostats.

Water Pump. — Trouble usually is caused by the packing. The type of pump with an adjustable packing nut can be tightened easily; it should be tightened just enough to stop the water from leaking past the packing along the pump shaft. When the self-adjusting type of pump leaks, the pump must be removed, and the pump shaft pressed out of the pump housing. A new packing unit is then installed, and the pump re-assembled.

In both types of pump, when the shaft, bushings or bearings develop side play, they should be replaced. If the shaft is worn where the packing fits, it should be replaced. The old bushings should be pressed out, new ones pressed in, and reamed to the new shaft for a fit without play, but not snug. Shafts operating in bearings that are sealed in lubricant must be replaced as a unit when the bearing fails. Heavy water-pump grease is used to lubricate the bushings on other pumps.

Water-pump noises are due to dry bearings or bushings, a loose pulley on the pump shaft, an impeller loose on the shaft, or too much end play in the shaft. This end play is caused by the pulley not having been pressed on far enough.

Fan and Fan Belt. — A fan shaft that is noisy because of inadequate lubrication is serviced in the same way as a pump shaft.

When the fan belt is too tight, there will be a continual squeaky noise and the belt will wear out rapidly because it is abnormally stretched. If the belt is too loose, it will squeak also. A loose belt will cause the engine to overheat and will affect the generator so that it will not be able to keep the battery charged. Broken pulley flanges or pulleys not properly aligned will cause excessive belt wear.

Radiator, Hose, Water Jackets, and Thermostats. — Besides a loose or broken fan belt, engine overheating is caused by water leaks through the pump packing; holes in the radiator; scale formation that clogs the radiator core or passages in the engine block; late ignition timing; obstructions across the front of the radiator core; rotted or collapsed hose connections; preignition; cylinder-head gasket assembled improperly, keeping the water from passing from the cylinder block to the cylinder head; thermostat installed or operating improperly; excessively heavy engine oil; anti-freeze in the cooling system of too low boiling point; excessively small bearing or piston clearances; and dragging brakes.

In other words, any undue friction either in the motion of the mechanical parts of the car or in the passage of water around the cooling system will overheat the engine. This overheating will cause a loss of power and efficiency of the engine and rapid wear of moving parts.

The hose connections, in time, will swell inward and restrict the passage of water, and the hose between the water pump and lower tank of the radiator sometimes collapses. Such hose, of course, should be replaced. Most thermostats are stamped with the temperature at which they should start to open to let the water pass from the engine to the radiator. The manufacturers' shop manuals also indicate these temperatures. These temperatures can be checked by placing the thermostat in a pail of water. While heating the water in the pail note the reading on a thermometer immersed in the water when the thermostat opens. This opening temperature is specified as between 152 and 160° F.

Rust and scale formation are the most common causes of engine overheating. The impurities in the water or the composition of the water in different localities will determine to a large extent just how much rust and scale will form. Air sucked into the system through the water pump will cause a great deal of rust, and is particularly damaging to aluminum-alloy cylinder heads. Oil and grease can get into the water past the cylinder-head gasket if it is not tightened down properly, or they can get in through the water pump where the bushing is lubricated. All these causes can band together to form scale and cause corrosion or rust in the system. Not only does this scale restrict the passage of water but, as the scale builds up on the radiator tubes, it makes it more difficult for the air drawn between the tubes by the fan to cool the water. In other words, scale formation on the radiator tubes impedes the flow of heat from the water to the air.

The use of an alkali or kerosene will cut the oil and grease in the cooling system but will not dissolve the scale formation. Acid will dissolve the scale but will not cut the oil and grease. Either one may help a little. The flow of water through a radiator, depending on the make and model of car, should be between 18 and 60 gpm, with an average around 30 gpm. A clogged radiator sometimes will reduce the water flow to as little as 3 gpm. Besides the use of an alkali or acid, a reverse flush is very effective in *all* radiators, and in *some* engine blocks, as all manufacturers do not recommend it in the latter. This reverse flush is made by means of a special nozzle which fits into the lower hose connection and introduces water and compressed air into the radiator. The reverse flow of water under pressure loosens the scale and rust and forces it out the upper radiator connection, to which a long hose reaching under the engine has been attached. The radiator and cylinder block should be given a reverse flush separately for best results.

Some engine blocks are provided with removable covers so that scale and corrosion may be scraped out of the water jackets. When replacing such a cover, a new gasket always should be installed.

CHAPTER XI

THE FUEL-FEED SYSTEM

The functions of the fuel-feed system are to store the fuel for the automobile engine; to supply it to the carburetor in required amounts and in proper condition; and to provide an indication to the driver of the amount of fuel in the tank. Accordingly, all fuel feed systems consist of: (1) a storage tank; (2) a fuel pump or other means for delivering the fuel from the supply tank to the carburetor; (3) a strainer for filtering the fuel; (4) a gage to indicate to the driver the level of gasoline in the fuel tank; and (5) necessary piping connections.

A fuel-feed system employing a mechanical diaphragm-type fuel pump, driven by the engine camshaft, to force the gasoline from the fuel tank to the carburetor is used on an overwhelming majority of American passenger cars. Other systems, either obsolete or in limited use, are the gravity system, the air-pressure system, and the vacuum system, each of which is described later in this chapter.

Mechanical Pump Pressure System. — The relation of the parts in this system is shown in Fig. 50.

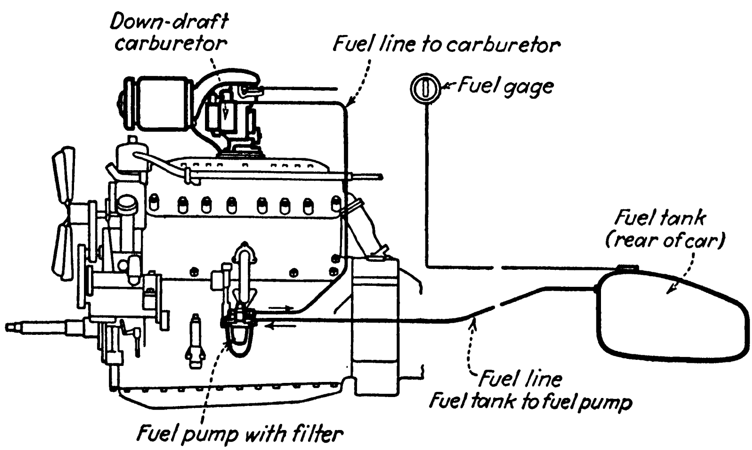


Fig. 50 — Typical passenger-car fuel-feed system

Tank. — Fuel tanks in practically all passenger cars are mounted in the rear of the vehicles and range in capacity from 5 to 26½ gal. An air vent is built into the filler neck. Tanks are often provided with vertical baffles to prevent surging of the fuel. A sump is provided at the bottom of many tanks to collect dirt and water and prevent them from reaching the pump and carburetor.

Pump. — To force the fuel from the tank to the carburetor in the required amounts in this system, a diaphragm-type fuel pump driven

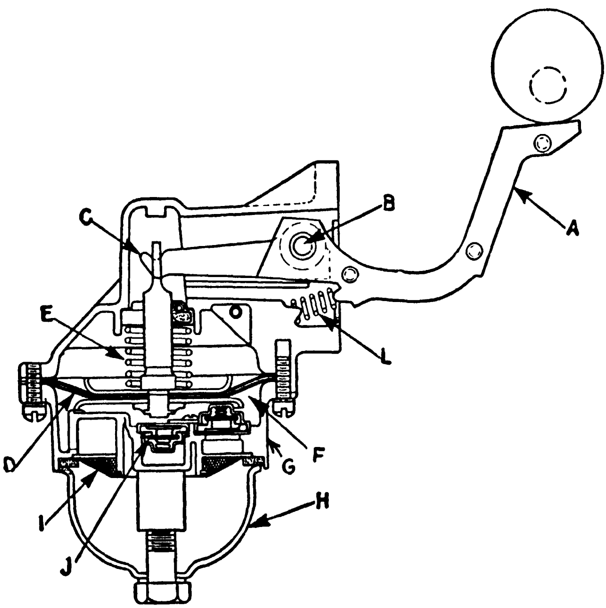


Fig. 51 — Diaphragm-type mechanical fuel pump

mechanically from the engine camshaft is used. This pump is mounted on the side of the crankcase as shown in Fig. 50. Fig. 51 shows a typical diaphragm-type pump. Following is the cycle of its operation:

The revolving camshaft with its cam (shown at the right) lowers rocker arm *A* which is pivoted at *B*. This movement pulls linkage *C*, together with diaphragm *D* which is held between metal discs, upward against pressure of the spring *E*, creating a vacuum in pump chamber *F*.

On the suction stroke, fuel from the rear tank enters through the inlet *G* into the sediment bowl *H*, through strainer *I* and suction valve into pump chamber *F*. On the return stroke, the pressure of

spring E pushes diaphragm D downward, forcing fuel from chamber F through outlet valve J through the outlet into the carburetor.

When the carburetor bowl is filled to the proper level, the float in the carburetor float chamber shuts off the carburetor inlet needle valve, thus creating a pressure in the pump chamber F. This pressure prevents the pressure of spring E from forcing diaphragm D downward, holding the diaphragm upward against spring pressure. The diaphragm is held in the upper position until the fuel level in the carburetor float chamber falls sufficiently to open the carburetor needle valve, thus relieving the pressure in the pump chamber F. At this time the diaphragm is free to rise and fall according to the motion of the cam.

Spring L is merely for the purpose of keeping operating lever A in constant contact with the cam to eliminate noise.

An air dome is provided over the pump discharge valve on some designs of fuel pump to provide more even flow of fuel to the carburetor. Maximum pressure of these pumps is about 5 lb per sq in.

On some pump designs the fuel pump is combined with a vacuum pump which acts as a booster for the vacuum-operated windshield wiper when the engine intake vacuum is low.

Fuel Strainer. — A fuel strainer or filter, shown at I in Fig. 51, is an integral part of the fuel pump. It comprises a metal or glass sediment bowl provided with a ring-type strainer (usually a fine-mesh metal screen) through which the fuel passes upward. Dust and water settle in the bowl which is removable for cleaning.

Gasoline Gage. — An electric gage with balanced coils is in practically universal use for indicating the level of the fuel in the gasoline tank. This gage is mounted on the instrument board in front of the driver.

The typical electric gasoline gage consists of two units — a dash unit and a tank unit. They are connected by a single wire as shown in Fig. 52. The return circuit is through ground connections on the two units as shown. The wire to the ignition switch is connected so as to open the gage circuit when the ignition is off so that the indicator of the gage operates only when the ignition key is turned on. The current consumption of the gage is so low (0.15 amp) as to cause no appreciable drain on the electrical system.

The dash or instrument-board unit consists essentially of two coils spaced 90 deg apart, with an armature and pointer assembly pivoted at the intersection of the coil axes. The right-hand coil is grounded as shown. The tank unit comprises a rheostat (resistance coil and movable contact), the contact being actuated by the float

to assume a position on the resistance corresponding to the position of the float in the fuel tank. This movable contact or brush is grounded as shown.

When the fuel tank is empty, the float arm and movable contact of the rheostat are moved so that all the resistance of the rheostat is cut out of the circuit. In this position the right coil of the dash unit is shorted out completely, and the current flows through the left coil only, attracting the armature and causing the indicator to assume the " empty " position at the extreme left.

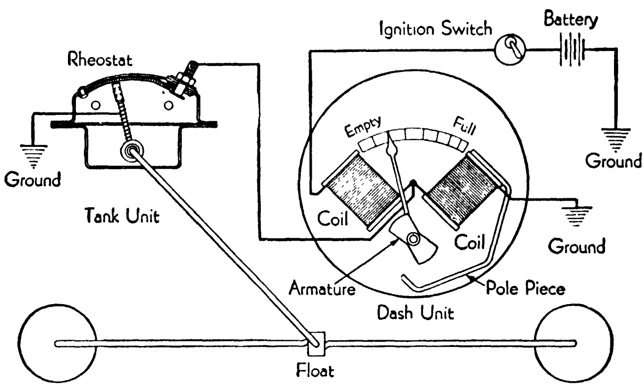


Fig. 52 — AC electric fuel gage with balanced coils

When the fuel tank is partly full, the float on the surface of the fuel rises, causing the float arm to move the contact to some position near the center of the resistance in the tank unit, thus including resistance in the circuit. In this position the current divides after flowing through the left coil of the dash unit, part flowing through the right coil and part flowing through the resistance in the tank unit. Thus the pointer is caused to assume a balanced or intermediate position between the coils, depending upon how much resistance has been introduced into the circuit — which corresponds to the level of the fuel in the tank.

When the tank is full, all the resistance has been cut in the circuit, and a still greater proportion of the current flows through the right coil, shifting the axis of the resultant magnetic field still farther and causing the pointer to move to the extreme right, indicating a full tank. An inertia damper is provided on the armature assembly to prevent vibration of the pointer on rough roads.

Many of these gasoline gages are designed to provide approximately 1 gal or less of reserve fuel when the pointer indicates that the fuel tank is empty. Variations in voltage supplied to these gages

do not affect their accuracy as their operation depends upon the proportion of electric current flowing through the coils of the dash unit, rather than on the actual strength of their magnetic fields.

Variations in the construction of the tank unit are made to suit different conditions. For small tanks, the movable contact is actuated directly by the float arm, as shown in Fig. 52, and the float may be either single or double. For large tanks the movable contact may be mounted on a vertical axis and driven from the float arm by bevel gears or their equivalent.

Other Types of Gasoline Gages. — Gages working on the hydrostatic principle and electric gages employing heated bi-metal strips have been used to indicate the fuel level in passenger cars.

The hydrostatic gage consists of a dash unit in which a glass U-tube containing a heavy red liquid indicates the gasoline level in the fuel tank on a graduated scale, a tank unit that applies pressure to the dash unit in proportion to the amount of gasoline in the tank, and an air line connecting the two units.

In the electric system employing bi-metal strips, the gage pointer is actuated by the bending of the bi-metal strip in the dash unit as this strip is heated or allowed to cool, according to the amount of fuel in the tank. Another bi-metal strip in the tank unit acts as a switch that controls the amount of heat applied to the dash bi-metal strip. This strip is caused to make and break the heater circuit with a movable contact, the position of which depends upon the tank fuel level.

Gravity Fuel-Feed System. — In this system, the storage tank is placed above the carburetor so that the gasoline will flow from it to the carburetor by gravity. The storage tank, usually located under the front seat, is provided with a filler cap which has an air vent through it. A gasoline outlet at the bottom generally leads to a sediment well, cut-off valve, and drain plug. The feed pipe to the carburetor takes off from the top of the sediment well. The need to move the fuel tank to a safer location at the rear of the motor vehicle below the level of the carburetor and wide adoption of downdraft carburetors which are designed to receive their fuel from beneath, are largely responsible for the virtual disappearance of this system from American passenger cars.

Vacuum Fuel System. — In this system the fuel is sucked from the fuel tank in the rear of the car to a small tank called a " vacuum tank " by means of the vacuum created in the intake manifold by the suction of the pistons on the intake stroke. The vacuum tank is installed under the hood above the carburetor. It consists essen-

tially of an upper " filling chamber " and a lower " emptying chamber." From the lower emptying chamber the fuel flows by gravity to the carburetor. The upper filling chamber is provided with a float-operated valve which controls the amount of fuel drawn from the fuel tank, according to the height of the fuel in the filling chamber, by shutting off the vacuum and opening the tank to the atmosphere and vice-versa. Some years ago this system was used widely but has since been superseded by the mechanical fuel pump pressure system.

Air-Pressure Fuel System. — In this system the fuel is forced from the fuel tank at the rear to the carburetor by air pressure in the fuel tank created by an air pump which is driven by the engine. An air-tight filler cap is used on the fuel tank to maintain the pressure. A pressure gage on the instrument board indicates the air pressure, and a safety relief valve is provided to prevent the pressure from reaching excessive values. An auxiliary hand pump is used to build up the pressure in the tank to start the vehicle after standing idle for a long time, or after the filler cap has been removed to supply gasoline to the tank.

Repairing Fuel-Feed Systems. — If fuel-pump trouble is suspected, a quick test is to disconnect the gasoline line from the pump to the carburetor and push the starter button. If gasoline comes out of the disconnected line, the fuel pump is working.

Before removing a fuel pump from service, all gasoline line connections from the gasoline tank to the pump should be checked. A poor connection or broken fuel line, of course, would prevent the pump from sucking gasoline from the fuel tank.

If it is seen that gasoline lines are in good condition and fuel does not spurt out of the disconnected carburetor line when the starter is operated, it is necessary to remove the fuel pump and take it apart for repairs. But, before it is taken apart, it is desirable to test it with a vacuum and pressure gage. The gage reading for a pump in good condition should be between 7 and 11 in. vacuum, and the needle on the gage should take about a minute to return to zero. Then, attach the gage to the pressure side of the pump and work the rocker arm again. A pump in good condition should show a specified reading. This reading will be as low as 2 lb per sq in. on some types and as high as 5 lb per sq in. on others. If neither of these gage readings is up to par, first mark the upper and lower housings of the pump so that they can be reassembled in the same position, then take the pump apart. Inspect the fiber valves and springs, rocker-arm spring, diaphragm and strainer screen. Clean all

parts and blow out with compressed air. Using a new diaphragm, assemble the pump and test again, re-install on the engine using a new gasket, and start up the engine to be sure the pump and connections are satisfactory.

Pump pressures must be watched carefully to see that they check with specifications. If the pump pressure is too high, the gasoline will force itself past the carburetor float needle valve, resulting in too rich a mixture from the main carburetor jet. To lessen the pressure, insert one or two more gaskets between the fuel pump and the engine block. This decreases the stroke of the rocker arm slightly.

The diaphragm is the cause of most fuel-pump trouble. Porousness or small holes in it will lessen the pump suction. With such a diaphragm the supply to the carburetor is reduced causing backfiring through the carburetor, which could be an indication of this trouble. A leaky diaphragm also will cause leakage of gasoline into the oil pan at the point where the pump is fastened to the cylinder block. A weak diaphragm return spring will lower the pump pressure, as will broken or worn rocker-arm linkage. Leaky pump cover gaskets and dirt in the gasoline line from the fuel tank will cut down the efficiency of the pump.

The vacuum booster (a part of some fuel pumps) is serviced in the same manner as is the pump. If its diaphragm leaks, it will cause the windshield wiper to work slowly or not at all during car acceleration or high-speed operation. Before looking for trouble in the vacuum booster, check all the connections between the booster and the windshield wiper, and between the booster and intake manifold to be sure that they are tight. A leaky booster diaphragm will allow oil to be sucked into the intake manifold directly from the oil pan through the connection between the pump and cylinder block. An indication of this trouble would be oil smoke coming out of the exhaust pipe.

Noisy action of the fuel pump or vacuum booster usually is caused by a worn rocker-arm pin or linkage.

CHAPTER XII

CARBURETORS, AIR CLEANERS, AND INTAKE MANIFOLDS

The carburetor is a device for atomizing and vaporizing the fuel and mixing it with the air in varying proportions to suit the changing operating conditions of motor-vehicle engines. This process of breaking up and mixing the gasoline with the air is called carburetion.

The difference between vaporization and atomization should be understood clearly. Vaporization is a change of state of the fuel from a liquid to a vapor, whereas atomization is a mechanical breaking up of the liquid fuel into small particles so that every minute particle of the fuel is surrounded by air. The ideal carburetor would pass a mixture of completely vaporized fuel and air in the proper proportion to the intake manifold and cylinders. Complete vaporization of the fuel is not achieved in present-day carburetors, however, because of the heavy nature of the fuel and other limitations. Heated intake manifolds and hot-spots in the manifold vaporize part of the finely divided mist or atomized fuel passed to the manifold by the carburetor. Vaporization of the gasoline in the mixture usually does not become complete until the end of the compression stroke in the cylinder — after heat has been applied in the intake manifold and heat and pressure during the compression stroke.

Air-Fuel Mixtures. — The theoretically perfect mixture of air and gasoline contains 15 parts by weight of air to 1 part of gasoline. When a uniform mixture of these proportions can be obtained, the mixture burns without leaving an excess of fuel or air. With a liquid fuel such as gasoline, however, it is difficult to obtain this perfect mixture, especially with low-test gasoline.

The air in the mixture furnishes the oxygen necessary for combustion. When there is too little air, insufficient oxygen is supplied to burn all the fuel, and some of the fuel is wasted. When there is too much air in the mixture, it will burn slowly and erratically, and power will be lost.

There is a range of proportions of air to fuel between which combustion will take place. The boundaries of this range are known as the upper limit of combustion and the lower limit of combustion.

The lower limit of combustion is generally between 7 to 10 parts of air by weight to 1 part of fuel. This mixture is barely explosive and burns with a reddish-yellow flame. The upper limit generally consists of about 20 parts of air by weight to 1 part of fuel. This mixture burns with a white flame, slowly and irregularly. The rate of burning and the exact upper and lower limits will vary slightly according to the pressure and temperature conditions in the cylinder, the character of the fuel, the uniformity of the mixture, and the design of the combustion chamber.

Mixture Requirements of Motor-Vehicle Engines. — For average "cruising" operation the air-fuel ratio ranges from 15:1 to 17:1. To obtain maximum power for quick acceleration and to negotiate grades speedily, the motor-vehicle engine requires a "rich" mixture containing about 12 to 13 parts of air by weight to 1 part of fuel. This is the so-called "maximum-power ratio." To start the engine from cold, even a richer mixture is necessary. For maximum economy (but with some loss of power) the mixture ratio employed is from 16:1 to 17:1. Thus the modern carburetor must be designed to furnish the proper proportions of fuel and air automatically to meet these varying operating conditions. To accomplish this purpose a number of designs and principles of carburetor operation are employed in passenger vehicles.

Simple Plain-Tube Carburetor. — As all modern commercial carburetors have evolved from the simple plain-tube carburetor, an explanation of its construction and operation will aid in understanding the basic principles underlying all carburetors.

Fig. 53 shows a simple plain-tube carburetor. In operation, the gasoline supply pumped from the fuel storage tank enters the float chamber *F* of the carburetor through the needle valve at the bottom. As the gasoline level rises, the float presses against the levers at the top of the float chamber. These levers are pivoted so that, as their outer ends are raised by the float, their inner ends, working in a collar or recess, force the needle valve downward into its seat, shutting off the flow of gasoline when the level of gasoline in the float chamber has reached the proper height. When the level of gasoline in the float tank falls below this level, the outer ends of the levers fall with the fuel level and the inner ends lift the needle valve, thus admitting gasoline to the tank. The height at which the gasoline is maintained in the float chamber *F* is governed by the nozzle of jet *G*. This level should stand about 1/16 in. below the orifice at the top of the jet. The gasoline is fed to the nozzle *G* from the float chamber through the pipe *E*. As the engine starts and the

pistons start to move up and down, air is drawn through the carburetor by the suction created by the pistons on their intake strokes. As indicated by the arrows in Fig. 53, the air passes the nozzle on its way to the cylinders. The suction created by the rush of air past the jet or nozzle causes the gasoline to be delivered to the mixing chamber above the nozzle in a fine spray. Since this suction is proportional to the velocity of the air passing the nozzle, a " venturi tube " X is used to increase the velocity.

A " venturi tube " is a tube or passage which is narrower at the center so that the area through which the air must pass is decreased considerably. As the same amount of air must pass through every point in the tube, its velocity will be greatest at the narrowest point. The more this area is reduced, the greater will be the velocity of the air, and the suction will be proportionately increased.

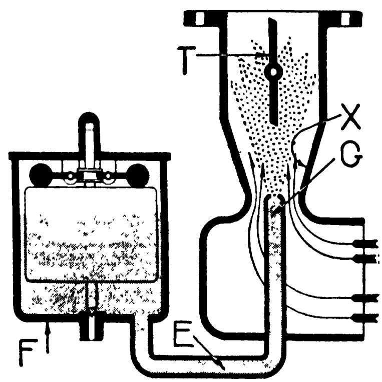


Fig. 53 — Simple plain-tube carburetor

The spray nozzle is usually located where the suction is greatest, which is just above the narrowest section of the venturi tube. The spray of gasoline from the nozzle and the air entering through the venturi tube are mixed together in the mixing chamber — located immediately above the spray nozzle. This produces a combustible mixture which passes through the intake manifold into the cylinders. Most of the fuel is atomized by the carburetor in the mixing chamber, only a small part being vaporized. The amount of the fuel vaporized in the carburetor depends upon the nature of the fuel; the temperature of the air, fuel, and engine parts; the amount of suction above the jet; and the degree to which the fuel is broken up or atomized. As stated previously, vaporization of the mixture usually is not complete until the end of the compression stroke in the cylinders.

The speed and power of the engine is controlled by the use of the throttle T, which is a form of damper placed between the mixing chamber and intake manifold. The more the throttle is closed, the greater will be the obstacle to the flow of the mixture placed in the passage and the less will be the quantity of mixture delivered to the cylinders. The decreased quantity of mixture gives a less powerful impulse to the pistons, and the engine's power is reduced

accordingly. As the throttle is opened, the power of the engine increases. Although opening the throttle usually increases the speed of the engine, this is not always the case as the load on the engine is also a factor. For example, opening the throttle when the motor vehicle is starting to climb a hill may or may not increase the vehicle's speed, depending upon the steepness of the hill and the amount the throttle is opened. In short, the throttle is simply a means to regulate the power of the engine by preventing it from pulling in a full charge of mixture during each suction stroke.

As the speed of the engine increases, the suction increases. The most serious limitation of the simple plain-tube carburetor is that flow of fuel from the jet increases under suction faster than does the corresponding flow of air, resulting in a mixture being delivered to the cylinders that gets richer as the speed increases. As it is essential to have practically the same proportions of air and gasoline at all speeds (except for starting, idling, and fast acceleration), it is necessary to provide automatic compensating devices on modern carburetors to maintain the desired mixture proportions at the higher speeds. These devices usually act either to increase the air supply automatically as the suction above the jet increases, or to increase the fuel supply automatically as the suction above the jet decreases. Metering rods, air-bled jets, "economizers," compound jets, and auxiliary air valves are devices commonly used to effect this compensation in commercial carburetors. The operation and construction of these devices as found in commercial carburetors will be described later in this chapter.

A rich mixture is necessary to start the engine, especially when cold. To provide this rich mixture a choke valve is inserted in the air-intake passage of the carburetor. During starting, this valve is operated to shut off partially the supply of air to the carburetor, thus enriching the mixture supplied to the cylinders by the carburetor. These choke valves are operated automatically by thermostats in most modern passenger-car carburetors; the valve is held in a partially closed position by the thermostat when the engine is being started, and is opened automatically as the engine heats up, gradually " leaning down " the mixture.

Motor-vehicle engines require a rich mixture for idling and low-speed operation, usually about 10 parts of air by weight to 1 part of fuel. To supply this mixture during starting most modern carburetors incorporate in their construction a special idling system consisting essentially of an idling fuel passage and idling nozzles. This system comes into action during starting, idling, and low-

speed operation, and is cut out when speeds of about 20 mph are reached. Details of this system will be given later.

When the suction through the carburetor is increased suddenly by quickly opening the throttle for rapid acceleration or extra power, the air, being lighter than the gasoline, will respond almost immediately and its flow will be accelerated very suddenly. This condition will result in the air rushing ahead of the gasoline particles and the proportion of air to gasoline will be greater until the inertia has been overcome and the gasoline particles have time to respond completely to the increased suction. In short, a sudden opening of the carburetor will tend to produce a lean mixture instead of the rich mixture required for rapid acceleration or increased power, due to the lagging of the gasoline. It is at this particular time that additional gasoline is most needed to compensate for this lagging and provide the proper rich mixture in the engine. Devices used in modern carburetors to accomplish this result are known as "accelerating pumps." These devices will be described later.

Carburetor Types. — Carburetors are classified: (1) according to the direction of airflow as downdraft or updraft; (2) according to the arrangement of the float chamber as "eccentric" or "concentric"; (3) according to the number of units as "single" or "dual."

Updraft and Downdraft Carburetors. — The simple plain-tube carburetor just described is of the "updraft" type, that is, the air enters at the bottom of the carburetor and leaves at the top. Most

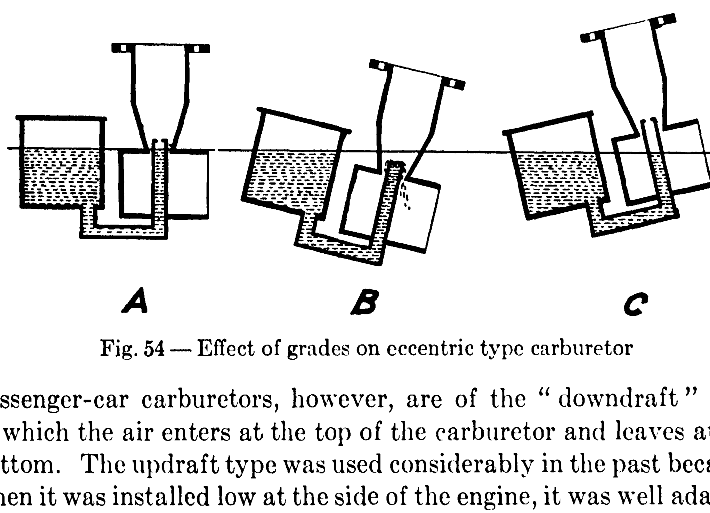


Fig. 54 — Effect of grades on eccentric type carburetor

passenger-car carburetors, however, are of the "downdraft" type in which the air enters at the top of the carburetor and leaves at the bottom. The updraft type was used considerably in the past because, when it was installed low at the side of the engine, it was well adapted to the gravity fuel-feed systems then in use. Advantages claimed for

the downdraft type are that it permits a manifold of larger cross-section because the fuel flows down into the manifold instead of being lifted up into it; the location of the carburetor above the engine is more accessible for inspection, adjustment, or repair; and the air entering the carburetor is cooler.

Concentric and Eccentric Float Chambers. — In the concentric float chamber the arrangement is such that the float chamber is placed around or surrounds the venturi tube or tubes. In the eccentric type, the float chamber is placed at the side of the venturi tube. Fig. 54 shows an eccentric type of float chamber in which the normal gasoline level is shown by the line in *A*. When the carburetor is tilted due to the car's ascending or descending a grade, the level will be changed as shown in *B* or *C*. This change in level at the jet may cause too much or too little gasoline to be supplied by the nozzle, giving incorrect mixtures. This difficulty will not be experienced with a concentric-float type of carburetor. The level at the nozzle always remains approximately constant, as shown in Fig. 55, by the levels *A–A*, *B–B*, *C–C*. Most modern carburetor float chambers are of the concentric type, or are constructed on the same principles.

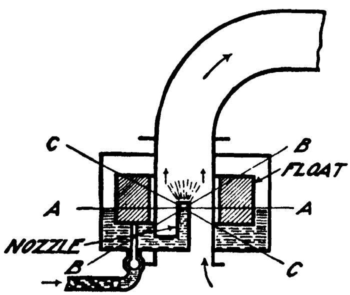


Fig. 55 — Effect of grades on concentric type carburetor

Single and Dual Carburetors. — Dual carburetors are provided with two barrels, each containing a fuel jet, venturi tube, and throttle, as compared with single carburetors which have only one barrel. Dual carburetors have a single air inlet, choke, and float chamber, although they frequently employ two floats, one for each jet. Passenger-car engines of eight or more cylinders are usually provided with dual carburetors — usually employed in conjunction with a double intake manifold. With a dual carburetor and double intake manifold on such an engine, the arrangement is such that each barrel of the dual carburetor feeds one branch of the intake manifold, feeding alternate cylinders in the firing order. This arrangement improves the uniformity of the distribution of the fuel mixture to the cylinders as there is less tendency for the suction strokes drawing from the same carburetor barrel to overlap.

Typical Modern Carburetor. — The carburetor to be described in the following paragraphs is typical of the majority in use on American passenger cars.

This carburetor falls naturally into five circuits:

1. Float circuit
2. Low-speed circuit
3. High-speed circuit
4. Accelerating-pump circuit
5. Choke circuit

By considering each of these circuits separately, study of the construction and operation of this carburetor is made easier.

Float Circuit. — This circuit operates on the same principles described earlier in this chapter in conjunction with the simple plain-

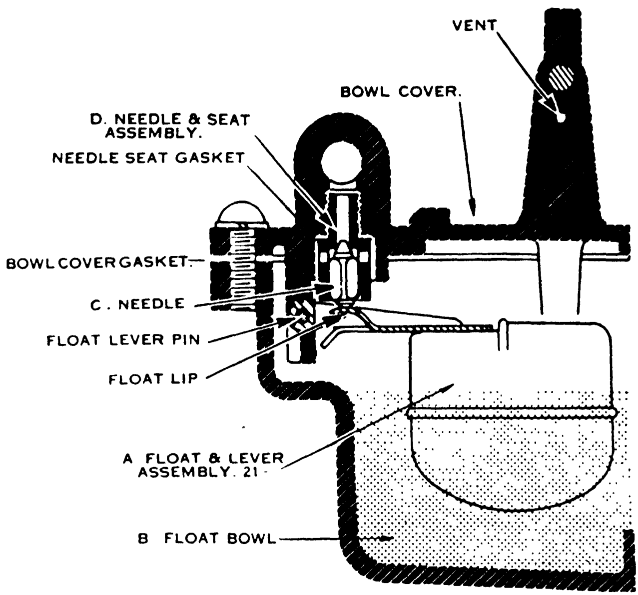


Fig. 56 — Details of float mechanism

tube carburetor. As shown in Fig. 56, the float circuit consists of gasoline pressure from the fuel pump, needle valve *C*, seat *D*, needle-seat gasket, float and lever assembly *A*, float bowl *B*, bowl cover gasket, and vent hole.

Low-Speed Circuit. — The idle or low-speed circuit completely controls the supply of gasoline to the engine during idle and light-load speeds up to approximately 20 mph, and it partially controls the supply for light-load speeds between 20 and 30 mph. The operation of the low-speed circuit is shown graphically in Fig. 57. The fuel flows from the float bowl through a low-speed jet, is mixed with

air and continues down the idling passage and out into the carburetor bore, through one or two port openings.

The idle or low-speed circuit (Fig. 58) consists of the low-speed jet *E*, bypass *F*, economizer, air bleed *G*, port opening *H*, idle adjusting screw *I*, throttle valve *J*, throttle shaft, and carburetor bore *K*.

During idling and low-speed operation of the engine, gasoline flows from the float bowl through the low-speed jet to the point where it is combined with a stream of air coming in through the by-

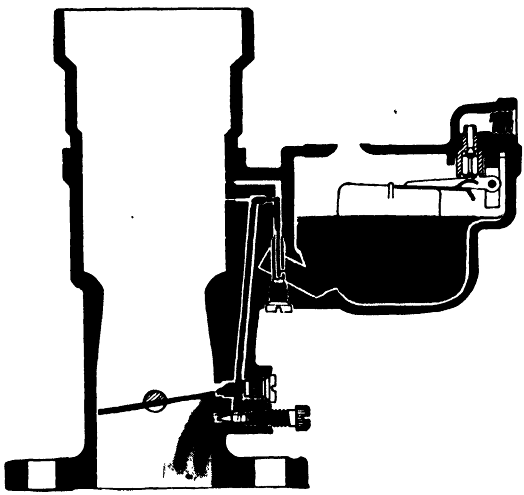


Fig. 57 — Operation of low-speed circuit

pass *F*. The combining of the stream of air with the stream of gasoline tends to atomize or break up the gasoline into a vapor.

The mixture of gasoline and air continues on through the economizer until it begins to pass the point where it is further combined with a stream of air coming in through the lower air bleed *G*. This air again tends to break the gasoline particles into a finer vapor. The gasoline and air mixture that flows downward in the passage from the lower air bleed *G* is still richer than idle mixture needs to be but, when it mixes with the air which has come past the throttle valve, it forms a combustible mixture of the right proportions for idle speed.

The idle port *H* is made in a variety of slotted shapes so that, as the throttle valve is opened, it will not only allow more air to come in past it, but will also uncover more of the idle port, allowing a greater quantity of the gasoline and air mixture to enter the carburetor throat from the idle mixture passage.

The idle position of the throttle is such that, at an idle speed of 6 mph, it leaves enough of the slotted port as reserve to cover the range in speed between idle and the time when the high-speed system begins to cut in.

The idle adjusting screw *I* varies the quality of the idle mixture.

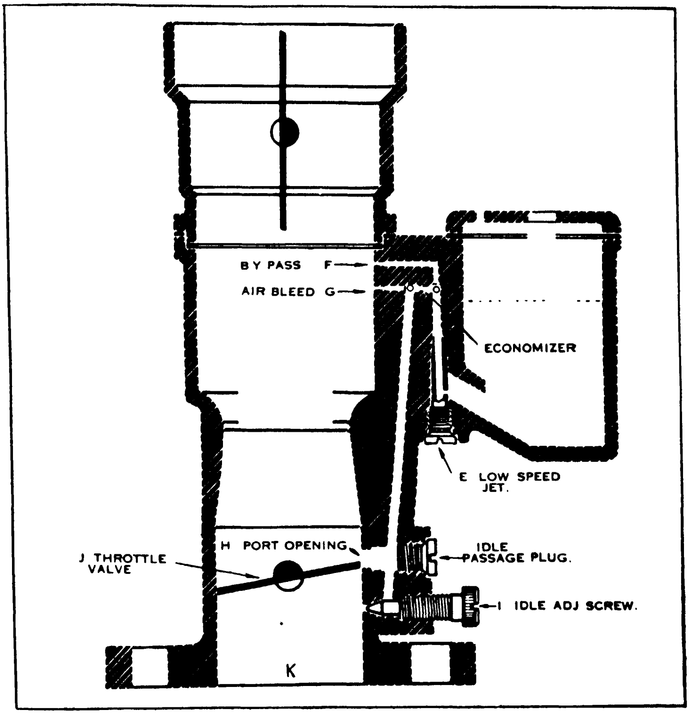


Fig. 58 — Details of idle or low-speed circuit

All the gasoline flowing from the float bowl during the idle period and at no-load speeds up to 20 mph flows through the small metering hole in the low-speed jet.

High-Speed Circuit. — Operation of the high-speed circuit is shown graphically in Fig. 59. Gasoline flows from the float bowl, through a metering jet, and out the main nozzle into the carburetor throat.

This circuit features a throttle-operated metering rod and a triple venturi. In the triple-venturi design the main nozzle discharges the fuel at an upward angle into the primary venturi against the downward air stream. The fuel, atomized in the primary venturi, is kept centrally located in the air stream by the surrounding blanket of air passing into the second venturi and again into the main

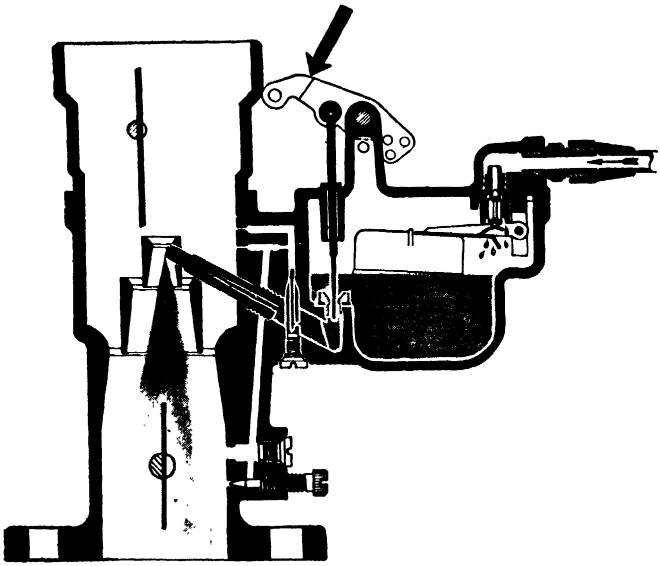


Fig. 59 — Operation of high-speed circuit

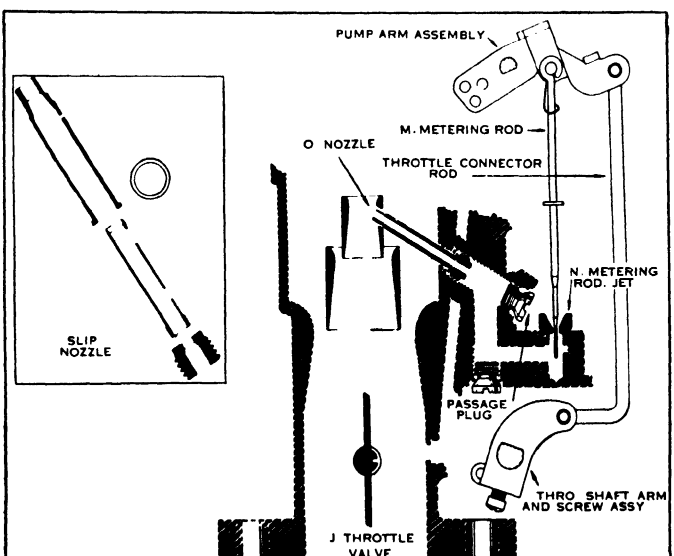


Fig. 60 — Details of high-speed circuit

venturi, offering protection against the fuel coming into contact with the walls of the carburetor. The triple venturi is shown in Figs. 59 and 60.

Referring to Fig. 60, the intermediate-speed and high-speed circuit consists of the metering rod *M*, metering jet *N*, nozzle *O*, and gasket, throttle valve *J*, metering-rod spring and disc.

As the throttle is opened wide enough for a speed of a little more than 20 mph, the velocity of the air flowing down through the carburetor throat creates a pressure slightly less than atmospheric at the tip of the main nozzle *O*.

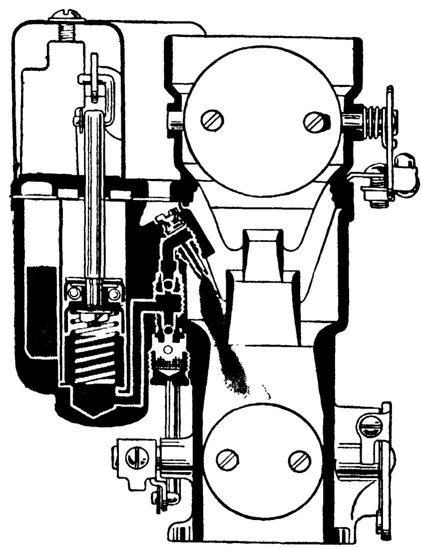


Fig. 61 — Operation of accelerating-pump circuit

Since the gasoline in the float bowl is acted upon by atmospheric pressure, the difference in pressure between the two points causes gasoline to flow from the bowl, through the metering jet, and out of the main nozzle into the throat of the carburetor.

As the speed increases from 20 mph, the high-speed system continues to cut in more and more, and the idle or low-speed system to cut out until the high-speed system is carrying the entire load and the idle system is doing nothing, as shown in Fig. 59.

At higher speeds, the area of the opening between the jet *N* and the metering rod *M* governs the amount of gasoline going into the engine. At top speed the smallest section of the rod is in the jet, uncovering the largest area. When the throttle is partly closed, it lowers the metering rod in the jet, reducing the flow of gasoline since a larger step of the metering rod is lowered into the jet.

Accelerating Pump Circuit. — Operation of the accelerating-pump circuit is shown graphically in Fig. 61 which shows the pump discharging gasoline into the cylinder barrel after the accelerator has been depressed.

This circuit, shown in Fig. 62, consists of the pump cylinder, pump arm assembly, connector link, pump plunger and rod assembly, plunger leather, plunger spring, intake valve, discharge valve, pump

strainer screen, pump disc check valve, pump jet, connector rod, and pump spring.

When the pump plunger and leather are first installed in the pump cylinder, a small amount of air is trapped between the piston and the top of the liquid gasoline. As the accelerator pedal is depressed, the pump plunger and leather are forced downward. This action compresses the trapped air, forces the gasoline to leave the

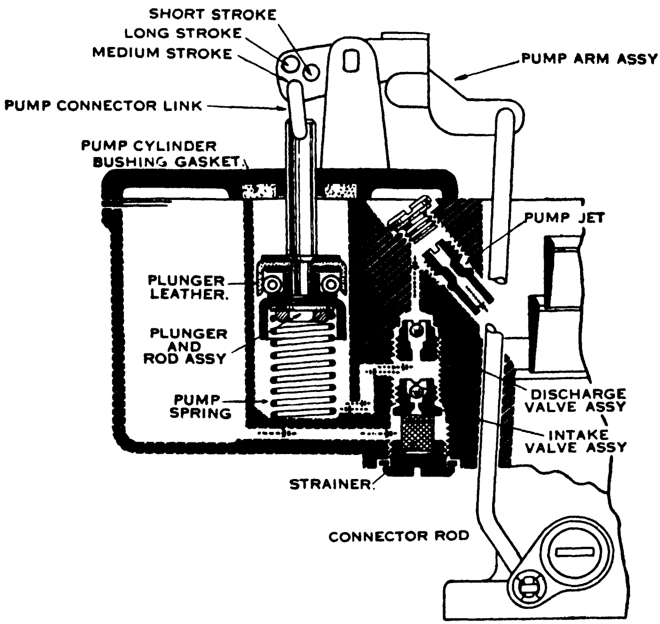


Fig. 62 — Details of accelerating-pump circuit

cylinder, closes the inlet valve, opens the discharge valve, closes the disc check valve, and discharges the gasoline into the throat of the carburetor.

The discharge is prolonged since the hole in the tip of the pump jet is small enough to restrict the flow of fuel so long as it is being forced out by the pump travel plus the expending of the trapped air. The prolonging of the pump discharge gives the gasoline in the high-speed system sufficient time to flow fast enough to satisfy the demands of the engine.

As the accelerator pedal is allowed to return to its original position, the accelerating pump plunger is lifted upward by the link. This action causes a partial vacuum in the pump cylinder which opens the intake valve, closes the discharge valve, and draws in a charge of gasoline.

Since the discharge valve is below the liquid level of the carburetor, gasoline would be drawn into the throat of the carburetor through the pump jet from the acceleration system during fixed throttle intermediate speeds and high speeds if it were not for the pump disc check valve or air bleed to the outside. This valve breaks the vacuum of the acceleration system by bleeding in air from the float bowl of the carburetor.

Choke Circuit. — This circuit is used only in starting and warming a motor, its purpose being to supply a rich mixture for starting.

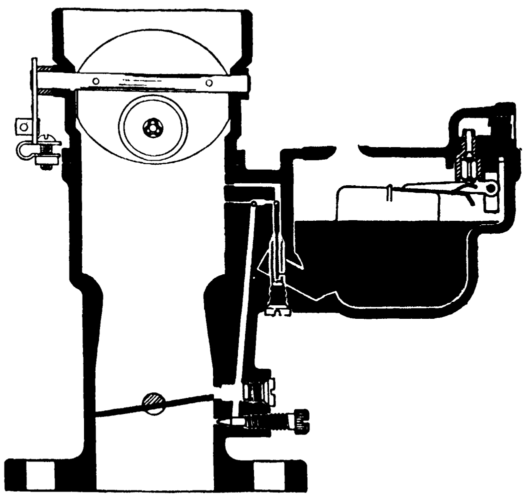


Fig. 63 — Operation of choke circuit

Fig. 63 shows its operation. The choke valve is held in a partly closed position by the thermostat, providing a rich mixture for starting. As shown in Fig. 64, it consists of a choker shaft and lever assembly, choker valve and screws, and a means of controlling the position of the valve. In the manual choke, a wire from the dash is connected to the choker shaft by a clamp and a screw. In the automatic choke, carburetor choke action is controlled by a spring of thermostatic metal. The automatic choke is shown in Fig. 65.

When the engine is cold, the tension of the thermostatic choke spring C holds the choke piston (D) at the top of its travel and the choke valve completely closed. This supplies the engine with a rich mixture for starting by throttling the air supply.

When the engine starts, the vacuum of the intake manifold acting upon the choke piston and the unbalanced choke valve partially opens the choke valve until it assumes the position where the tension

of the thermostatic choke spring is balanced by the pull of the vacuum on the spring and valve.

As the engine warms up, slots in the sides of the choke piston cylinder allow the vacuum of the intake manifold to draw warm air from the exhaust-manifold stove through the tube at the left, through the choke air-cleaner screen *J*, past the thermostatic spring *C*, and into the intake manifold.

This flow of warm air heats the thermostatic spring and causes it to decrease its tension. The pull of the vacuum on the piston

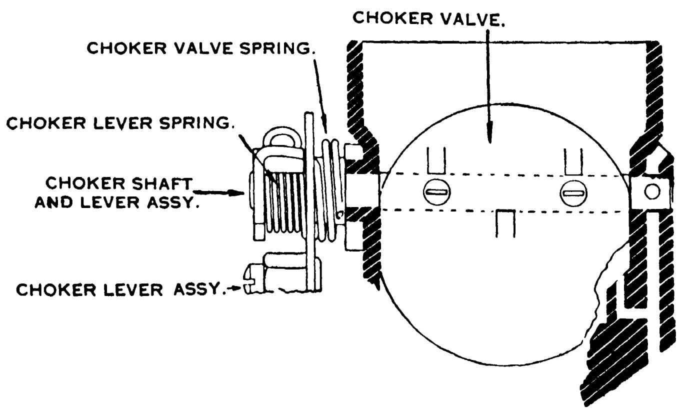


Fig. 64 — Details of choke circuit

working against the decreasing tension of the spring, gradually opens the choke in such a way that it is fully open when the engine is warm enough to run on the regular idle mixture.

If, during the warm-up period, the engine is accelerated, the corresponding drop off in vacuum, which automatically comes with acceleration, allows the thermostatic spring momentarily to close the choke partially, providing the engine with a mixture rich enough for acceleration.

Since on wide-open throttle at low engine speeds the intake manifold vacuum drops to practically zero, it is possible, at the beginning of the warm-up period while the thermostatic spring still retains some tension, for the choke to be closed by the spring, thereby causing an excessively rich mixture. To prevent this condition, an arrangement is made in the choke linkage so that, on all wide-open throttle operations, the choke is held open. (This arrangement is called the " lockout.")

During the warm-up period, it is necessary to run the engine at

approximately 10 to 15 mph no-load speed to keep it from stalling. This is done by having the high spot on the cam come under the idle-speed adjusting screw, holding the throttle open sufficiently to provide the necessary engine speed. This is called the " fast idle."

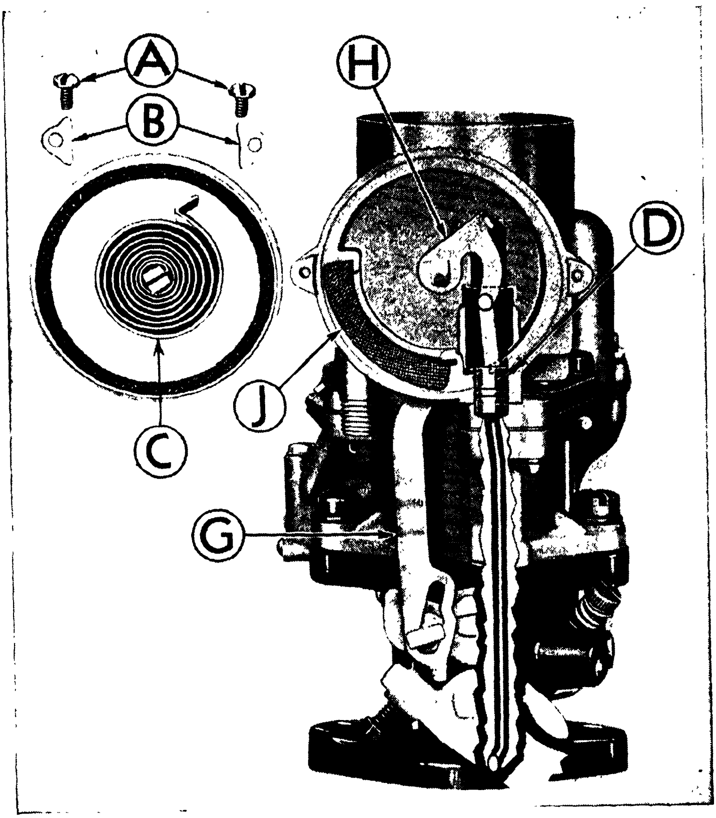


Fig. 65 — Details of automatic choke

When the engine warms up sufficiently to run at regular idle speed without stalling, the operation of the choke moves the cam out from under the idle-speed adjusting screw.

If, for any reason during the starting period, the engine is flooded, it is necessary to be able to hold the choke open sufficiently to allow the engine to clean the excessive gasoline out of the intake manifold. This is accomplished by an arrangement of the throttle lever and choke linkage whereby depressing the accelerating pedal to the floorboard forces the choke open sufficiently to allow the engine to clean out the intake manifold. This device is called the " unloader."

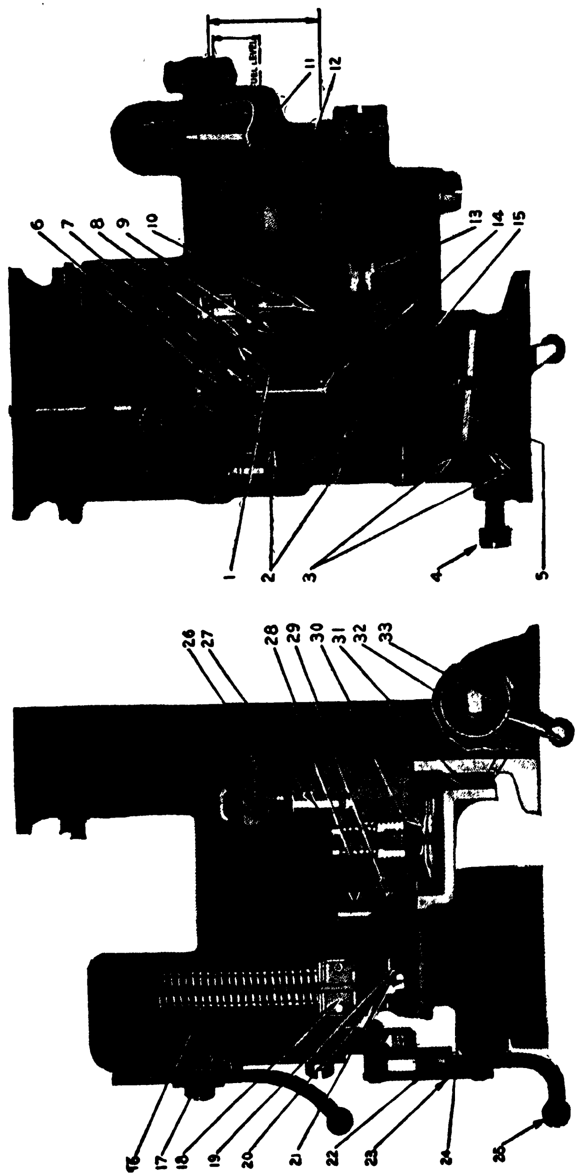


Fig. 66 — Dual downdraft carburetor using economizer

Other Common Commercial Types. — Fig. 66 illustrates a carburetor used on a popular line of cars. It is a dual downdraft type employing a float circuit, idle circuit, and accelerating pump similar to the typical carburetor just described in detail. An " economizer " is used to control the mixture strength.

At intermediate speed the gasoline flows from the metering jet (13) to the passages (9) and (7) and then discharges out the main nozzle (14) into venturi (15).

When the car attains a predetermined speed, the economizer (30) opens and admits an extra amount of fuel from the bowl (12) into the economizer restriction (29) and into the fuel passages (28).

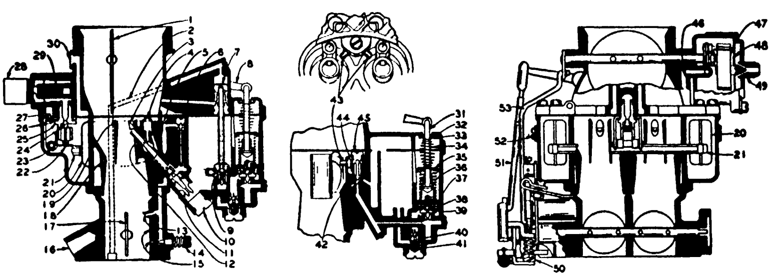


Fig. 67 — Dual downdraft carburetor employing an air-bled jet

The opening of the economizer is dependent on the car speed and the manifold vacuum which acts on the economizer through the passage (31) and the passage (32) which has its outlet below the throttle valves. This type of carburetor does not incorporate an automatic choke as regular equipment.

In another dual downdraft design used on medium and high-priced models (Fig. 67), an " air-bled jet " is used to maintain the proper mixture proportions throughout the entire operating range. In operation, the main metering jets (11), of fixed type, control the flow of gasoline during intermediate or part-throttle operation up to approximately 75 mph. From the metering jet fuel passes into the main discharge jet (3) where it is mixed with air from the " high-speed air bleeder " (4) and flows into the carburetor barrel and the intake manifold. It is evident that, as the suction at the jet increases, more and more air will go through the high-speed air bleeder (4) to provide the amount of air dilution required to maintain the proper mixture proportions at high speeds.

The float chamber that supplies both barrels of this carburetor completely surrounds the entire body. There are two floats, one on each side. For each barrel there is a set of venturi tubes, a main

metering jet, and idle system with an adjustable needle, a throttle valve, and a pump discharge nozzle. An accelerating pump is connected directly to the throttle. The economizer is controlled by manifold vacuum.

Other Compensating Devices. — As stated previously, various devices are employed in modern carburetors to compensate for the fundamental limitation of the plain-tube carburetor — that the flow of fuel from the jet increases faster under suction than the flow of air as the speed of the engine increases. Two such compensating devices that are, or have been, in common use and not incorporated in the carburetors just described are the auxiliary air valve and the compound jet.

Auxiliary Air Valve. — The auxiliary air valve (Fig. 68) controls the mixture strength by automatically admitting air into the mixture as the suction and engine speed increase. The auxiliary

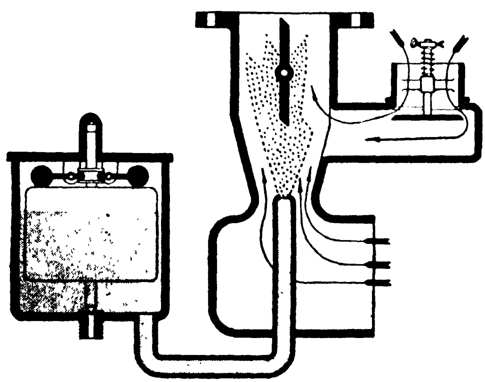


Fig. 68 — Simple auxiliary-air-valve carburetor

air valve is held closed against its seat at low speeds when the suction in the carburetor is low. At high speeds as the suction in the carburetor reaches a predetermined value, outside atmospheric pressure opens the valve automatically against the action of the spring, allowing the air to enter the mixing chamber of the carburetor, thus diluting the over-rich mixture. By adjustment of the spring the time and amount of opening of the valve can be controlled.

Sometimes an auxiliary fuel jet is provided in the same chamber with the auxiliary air valve so that the jet is in the path of the air flowing in from the air valve. The effect of this auxiliary jet is that a lean mixture is used to dilute the mixture in the carburetor barrel instead of air. This jet is provided to overcome the tendency of

auxiliary-air-valve carburetors to supply a mixture that is too lean at high speeds.

Compound Jets. — This arrangement is shown in Fig. 69. It combines a main jet *G*, which operates the same as the main jet in a plain-tube carburetor, with a "constant-flow" jet *H*. The deficiency of the main jet — that the mixture grows richer as the suction increases — is compensated for by the characteristics of the constant-flow jet which produces a mixture which grows leaner as

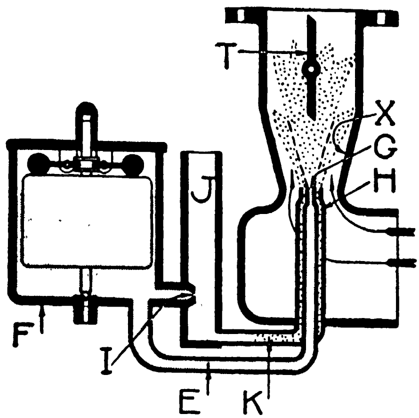


Fig. 69 — Simple compound-jet carburetor

the suction increases. One supplements the other so that, at every engine speed, there is a constant ratio of air and gasoline to support efficient combustion. The constant-flow jet is provided with a passage to the atmosphere called an "air well" *J* and a constant-flow nozzle *I*. The result is that the constant-flow nozzle is independent of the suction in the venturi because the fuel in the well is always under atmospheric pressure, the size of the orifice in the constant-flow nozzle *I* alone determining the amount of fuel furnished. Therefore the amount of fuel flowing through the nozzle is constant. When the operating conditions are such that the constant-flow jet *H* and the well *J* are emptied faster than fuel flows through the nozzle *I*, air will enter the jet *H* from the well *J* and mix with the fuel, thus providing a leaner mixture.

Compound Carburetion. — As introduced in 1941, this type of carburetion employs two dual carburetors in the same intake manifold. The front carburetor is a complete dual unit. The rear carburetor, however, is provided only with an idling circuit, main circuit,

and throttle; the starter switch, choke, accelerating pump, and power bypass are omitted.

In operation, the idling circuits of both carburetors function during idling. As the accelerator is depressed during part-throttle operation, the main circuit of the front carburetor comes into play (as explained earlier in this chapter) to supplement the idling circuits of both carburetors. The throttle connections from the accelerator are arranged so that the main circuit of the rear carburetor

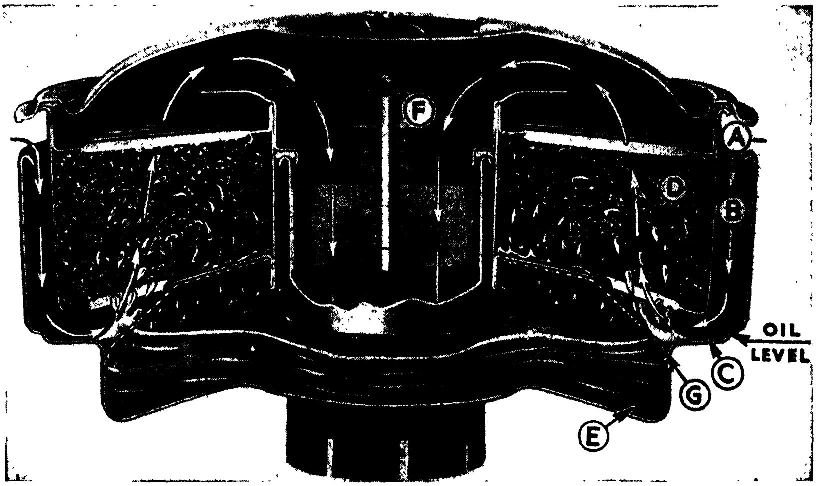


Fig. 70 — Oil-bath-type air cleaner

is not brought into action to help the front carburetor until the throttle of the front carburetor is about half way open. The rear carburetor is controlled by a damper valve as well as by its throttle. This damper valve is opened by air passage and closed by weight load; therefore it limits the amount of mixture fed by the rear carburetor at low speeds and full throttle.

Since each dual carburetor used is smaller than the single dual carburetor needed to operate the same engine, it is claimed that this system makes possible greater fuel economy as well as greater power.

Air Cleaner. — Air cleaners are provided in virtually all passenger cars to protect the engine from excessive wear, deposits, and sludge that otherwise might result from the dust and dirt drawn into the engine with the carburetor air.

Oil-bath types of air cleaners, of which Fig. 70 is typical, are used in an overwhelming majority of passenger cars and trucks. They are furnished with or without an in-built carburetor silencer.

In operation, dusty air enters the cleaner through opening *A* between the shell and the top cover, passing downward through the annular passage *B*. The air strikes shelf *C*, throwing heavier dust particles into the oiled surface and reverses upward into the filter element *D*. Oil is carried upward into the filter element in a predetermined amount which automatically oils and washes it. Dirt not directly precipitated by the oil is caught on the filter element and washed back into the oil sump *E*. Cleaned air passes out of the filter element to the carburetor through the passageway *F*. A perforated baffle *G*, prevents oil pull-over on large engines. Filter elements are pre-oiled; the manufacturer recommends that they should be replaced every 5000 miles for average operating conditions, oftener for operating in extremely dusty localities. The air cleaner is generally installed on top of the carburetor.

Intake Manifold. — The intake manifold provides a suitable passage to conduct the fuel mixture from the carburetor to the cylinders. Modern intake manifolds also are heated to assist in the vaporization of the gasoline in the mixture, particularly to break up the heavy fractions of the fuel. Heat usually is supplied from the exhaust gases or cooling water; sometimes " hot-spots " are provided at points where the fuel strikes and otherwise is likely to condense and collect. The heat supplied to some designs of intake manifold is controlled by a thermostat so that all the exhaust gas possible is deflected to heat the intake manifold when the engine is cold, and less and less heat is applied as the engine warms up. In applying heat to intake manifolds, it is usual so to design the intake manifold that the atomized or liquid fuel is separated from the remainder of the charge and is caused to come into contact with a " hot-spot " which is heated by the exhaust gases, rather than to heat the entire manifold. The disadvantage of the latter method is that the entire fuel charge is heated; as a result it expands and reduces the weight of the mixture charge drawn into the cylinders.

Principles of good intake manifold design are that the path from the carburetor to the cylinders be as short and smooth as possible so as to give the fuel a minimum opportunity to condense and collect on the manifold walls. For good distribution it also is desirable to have the distance of each of the cylinders from the carburetor approximately equal. Intake manifolds are usually of cast iron.

As mentioned previously, dual carburetors usually are provided with intake manifolds having two branches, one for each barrel of the carburetor. Each of these branches feeds half of the engine cylinders, thereby preventing overlapping of strokes in the manifold

and improving uniformity of distribution. In some in-line engines the intake and exhaust manifolds are cast together in the same piece, thus making it easy for the intake manifold to be heated by the exhaust gases. Typical arrangements of intake manifolds on in-line and V-type engines are shown in Figs. 71 and 72.

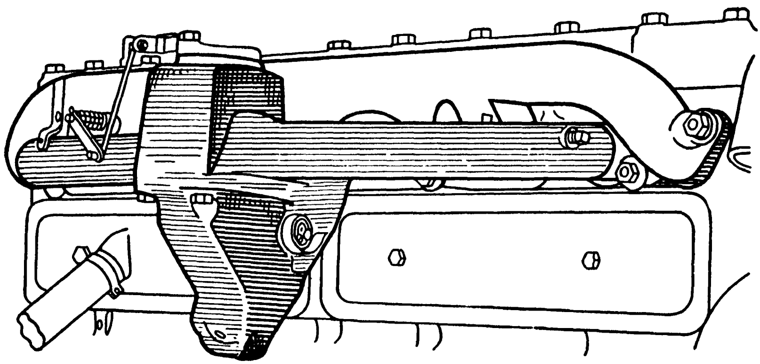


Fig. 71 — Intake manifold on in-line engine

Servicing Carburetors. — Assuming that the valve timing is correct, good engine performance depends on compression, ignition, and carburetion. The longer a car is run, the more change there is likely to be in these three functions. Compression changes are due to wear of the piston rings and valves; ignition and carburetion changes also are caused by normal wear or, more often, by experimentation in adjustments for better engine performance.

Each of the three must be in good adjustment for maximum performance.

It is best to make certain that the compression is up to par, and that all parts of the ignition system are in good condition and properly timed, *before* going to work on the carburetor, because carburetion is the most delicately adjusted of the three functions mentioned.

Complete carburetor overhaul should be attempted only by a mechanic who has been trained for this particular work, and has all the necessary carburetor tools and specifications.

In most cases, however, a thorough cleaning and minor adjustments will put a carburetor in good order.

Carburetor complaints are usually:

1. That too much gasoline is being used or that the carburetor chokes up.

2. That the carburetor does not enable the engine to " pick up " quickly, or to deliver sufficient power.
3. That the carburetor causes hard starting, uneven idling, or stalling of the engine.

Following are listed the causes and remedies of the foregoing troubles: Before taking a carburetor apart, it is necessary to refer to the car manufacturer's service manual for the special tools needed

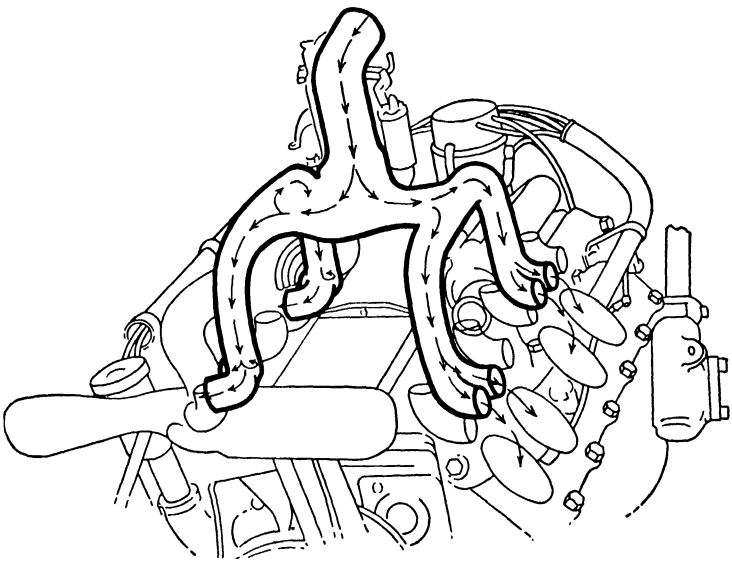


Fig. 72 — Intake manifold on V-8 engine

and the specifications to be adhered to. If the special tools are not available, only the parts that can be taken out easily with a screwdriver or ordinary hand tools should be removed. Clean all parts in gasoline and blow them out with compressed air. Re-assemble, using new parts when necessary.

When the engine uses too much gasoline or chokes up, it is usually caused by improper use of the manual choke, or by improper adjustment or mechanical trouble with the automatic choke. If the choke is adjusted on the rich side, the choke valve will not open all the way when the engine is hot, and insufficient air will enter to give the right gasoline and air proportion. This condition may also make the car hard to start, causing it to start and stall immediately, particularly if the air strainer in the choke control is clogged with carbon. The vacuum which acts from the intake mani-

fold through this strainer should help to open the choke a small amount as soon as the engine starts. If the choke valve or any of its linkage sticks at any point, it should be freed. Any automatic choke trouble should be checked with the manufacturer's specifications. If the fuel pump pressure is too high, it will force gasoline past the float needle valve and raise the level of gasoline in the carburetor float chamber above the specified point. This condition will cause an excessively rich mixture because the excess of gasoline in the float chamber will overflow the main jet, and cause fuel wastage, resulting in possible "loading up" and poor engine performance. To lessen this pressure from the fuel pump, an additional gasket should be placed between the fuel pump and engine block, as explained in the repair section of the preceding chapter. The float itself may be adjusted to ride too high, causing the same trouble.

On carburetors employing a metering rod, this rod will wear and, in time, will allow more gasoline to be metered into the engine than necessary. This rod should be checked for proper size and adjustment.

The air cleaner often gets clogged with dust and dirt. This difficulty will restrict the passage of air, just as will a partly closed choke. The air cleaner should be cleaned in gasoline more often when the cars are driven on dusty roads than on paved roads. On oil-bath types of cleaner, the oil should be changed and the unit cleaned. Particles of dirt lodged in any of the narrow passages will cause poor performance and the use of too much gasoline in the carburetor. Clean and blow out with air the main jet and all other jets; the air bleeds; the float needle valve and seat; the economizer valve which, if it does not seat properly, will cause high gasoline consumption at all car speeds; the accelerating pump bypass jet, the valve of which must seat to give gasoline economy; and the idle discharge holes.

If the engine does not pick up quickly or does not seem to have sufficient power, the float level may be too low, thereby failing to supply enough gasoline in the main jet. A clogged metering jet may cause backfiring in the carburetor. A dirty or clogged economizer valve will not work at high speed and will cause loss of power. The economizer vacuum piston or accelerating pump piston which does not work properly will cause the same trouble and should be cleaned, or the vacuum line may leak. Any vacuum line, such as those to the spark control, windshield wiper, or automatic choke, may leak, causing too much air to enter the intake manifold, resulting in a

poor mixture and lack of power or engine miss, sometimes accompanied by a hissing sound.

In addition to the foregoing, lack of quick acceleration is often due to a worn accelerating pump piston leather. This leather should be tested and, if necessary, replaced. The pump lever may be adjusted for too long or too short a stroke. In such case, it should be adjusted to specifications. The pump check valve may not seat properly due to dirt, causing poor pick-up.

Difficult starting is caused by a low float level; dirt anywhere in the system; choke not closing fully; leaks in a vacuum connection; or the fuel pump not delivering up to specifications. These troubles also may cause uneven idling or stalling. Poor idling also may be caused by a clogged idling passage or a clogged idling air bleed; poor idling screw adjustment or the idle setscrew adjustment set too low. Stalling can be caused by any of the foregoing conditions and also by dirt collecting in any part of the system.

CHAPTER XIII

THE EXHAUST SYSTEM

The exhaust system collects the exhaust gases from the cylinders of the motor-vehicle engine and conducts them to the rear of the car where they are discharged to the atmosphere, and does so with a minimum of power loss, noise, vibration, and transfer of heat to the car body. The system comprises essentially an exhaust manifold bolted to the cylinder block or head, a muffler attached to one side of the frame toward the rear of the car, exhaust pipes that connect the exhaust manifold and the muffler, and a tail pipe that leads from the muffler to the rear of the car to discharge the exhaust gases to the atmosphere. In some cases, particularly in V-type engines, dual exhaust systems are employed, each unit of which has an intake manifold, muffler, and piping. To prevent power loss, the exhaust system must present a minimum of resistance to the flow of the exhaust gases, as such resistance builds up back pressure in the exhaust system that opposes the working pressure in the cylinders.

Exhaust manifold. — The exhaust manifold collects the exhaust gases from the exhaust ports of the various cylinders and conducts them from each end to a central exhaust passage. The exhaust

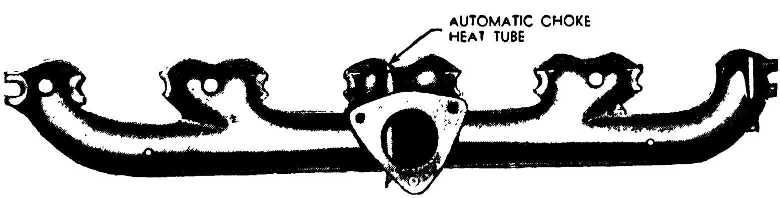


Fig. 73 — Exhaust manifold for eight-cylinder in-line passenger-car engine

manifold is usually made of cast iron. Fig. 73 shows an exhaust manifold for an eight-cylinder in-line, valve-in-head engine. Exhaust manifolds are designed to avoid as much as possible the overlapping of exhaust strokes, thus keeping the back pressure to a minimum. This is often done by dividing the exhaust manifold into two or more branches so that no two cylinders will exhaust into the same branch at the same time. Back pressure is reduced also by

designing the exhaust manifold with capacity ample to eliminate any restrictions to flow, and by incorporating streamlining and large-radius bends into the design. A heat tube provided to furnish heat to the automatic choke unit of the carburetor is shown in Fig. 73.

The center portion of the exhaust manifold often is connected to the intake manifold through a heat trap and exhaust damper as shown in Fig. 74. The damper is controlled thermostatically to deflect the hot exhaust gases upward and around the intake manifold when the temperature of the engine is below a predetermined value. This heat control is automatic. When the engine is cold,

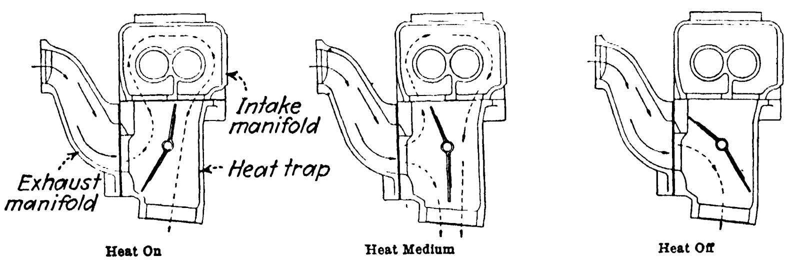


Fig. 74 — Heat control valve operation

all the exhaust gases are bypassed around the intake manifold, as shown at the left in Fig. 74. As the engine warms up, part of the exhaust gases are bypassed and part flow directly out the exit, as shown in the center sketch of Fig. 74. When the engine is fully warmed up, none of the gas is bypassed around the intake manifold, as shown at the right. In Fig. 74 it can be noted that the heat-control valve is offset, being longer on one side than the other. This design permits the pressure of the exhaust gases to force the valve wide open when the engine is operating under full-throttle conditions.

Manual control of the heat damper valve instead of the automatic control just described is provided in some designs. Such manual controls provide stops or positions corresponding to the seasons of the year, with maximum heating of the intake manifold for winter operation. In other types of exhaust manifold, there is a connection from the heat-control valve to the dash so that the driver can control the intake manifold heat manually from the driver's compartment.

The flanged joints between the cylinder head and exhaust manifold are sealed either with a special compound or by means of gaskets.

Exhaust Pipes. — Exhaust pipes are generally about 2 in. in outside diameter and 1/16 in. thick or less. The connection between the exhaust manifold and the exhaust pipe leading to the muffler is flanged. Both exhaust pipes and muffler usually are mounted so as to eliminate metal-to-metal contact, to prevent the transfer of vibration and exhaust noise to the car body. This insulation is accomplished by interposing rubber-impregnated fabric, rubber, or similar material between the exhaust pipes, mufflers, and the mounting brackets. The supports also allow for engine movement and for expansion and contraction with temperature changes.

Muffler. — If the engine were allowed to exhaust directly to the atmosphere without the use of a muffler, the noise of the escaping gases would sound like the firing of a gun, and be very disagreeable to the occupants of the vehicle. The cause of the noise in such a case is the large difference in pressure between the expanding exhaust gases and the atmosphere. The function of the muffler, therefore, is to reduce the pressure of the exhaust gases sufficiently to permit them to be discharged to the atmosphere silently enough to meet present high standards of quiet vehicle operation. To reduce the pressure, the exhaust gases are permitted to expand slowly and to cool in the muffler. On the other hand, the muffler must not cause any appreciable restriction to flow that will raise the back pressure excessively. Even the best of mufflers, however, cause a loss of power amounting to several per cent. The capacity of the muffler should be sufficiently large to permit the gases to expand to nearly atmospheric pressure before they are discharged into the air. As the gases are delayed in their passage through the muffler from the cylinders to the open air, their temperature is reduced, thus decreasing their volume.

Straight-Through Muffler. — This type of muffler (Fig. 75) is growing in popularity because of its simplicity and because it presents slight restriction to the flow of gases. It comprises a straight-through passageway from the exhaust pipe to the tail pipe. This passageway has a large number of small perforated holes cut in its surface, as shown in the illustration, which open into a large concentric diffusion chamber. In some designs this diffusion chamber is filled with a sound-absorbing and heat-resistant material, such as steel wool; in others, it is not. When the pressure in the passageway is at its maximum, some of the exhaust gases will be forced through the perforations in the wall of the passageway into the diffusion chamber where they will expand and the sound waves will be absorbed in the insulation filling (if present). When the pressure in

the passageway is at a minimum, some of the exhaust gases will return to the passageway from the diffusion chamber, thus equalizing the variations in pressure. Some designs of straight-through mufflers also incorporate a " resonance chamber " at one end or in the middle to reduce the pressure and noise still further.

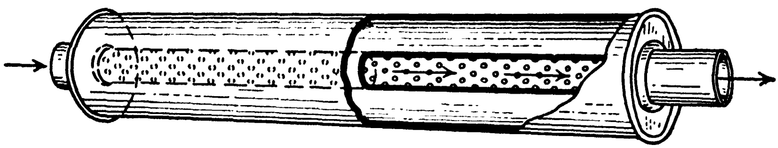


Fig. 75 — Straight-through muffler

Other Muffler Types. — One type is provided with a series of concentric chambers embodying holes and baffles through which the gases are conducted to reduce their velocity and pressure slowly.

Another type has three perforated tubes in addition to the inlet and outlet tubes and a resonance chamber through which the gases are caused to flow. The purpose of the resonance chamber is to damp out the noises that are likely to occur during coasting.

The outer shell of one design of muffler is made oval in shape to permit adequate clearance with the ground. Many of the outer shells of mufflers are made of steel coated with a lead-tin alloy (terne plate) to resist corrosion, particularly that caused by the exhaust condensate. To provide for drainage of the condensate from the exhaust gases, and further to resist corrosion, most mufflers are provided with small drain holes in the outside shell.

Muffler Service. — A clogged muffler, exhaust pipe, or tail pipe will cause a back pressure on the pistons and a loss of power. The end of the tail pipe sometimes gets bent, restricting the flow of exhaust gas, also causing a back pressure. These are rare occurrences, but must be considered when checking for loss of engine power. Mufflers usually are replaced rather than repaired. Manifold-to-engine-block gaskets, when used, should be renewed every time the manifold is taken off in order to insure a good joint. Exhaust gas is dangerous and every precaution should be taken to insure that it does not leak into the car body.

CHAPTER XIV

MAGNETISM

To understand ignition, starting, and lighting systems thoroughly, a preliminary knowledge of magnetism and elementary electricity is necessary. Only the most simple and fundamental electrical principles will be taken up, but this and the following chapter must be thoroughly understood or trouble will be encountered when the electrical apparatus used on a motor vehicle is studied. The preliminary discussion will be divided into two parts: (1) magnetism and (2) elementary electricity.

Magnet. — The name magnet was first applied to certain brown-colored stones taken from the earth which possessed the peculiar property of attracting small pieces of iron ore. When freely suspended by a string at the center this stone possessed the important property of pointing north and south, hence, it was given the name of "lodestone" (meaning leading stone). Hence, a magnet may be defined as a piece of steel or other substance which possesses the properties of attracting other pieces of steel or iron, and of pointing north and south when freely suspended in a horizontal position.

The compass needle is nothing more than a small bar magnet pivoted at the center so that it is free to turn in any direction like the lodestone. It will always point north and south, the same end pointing north each time. The ends of a magnet are termed its poles. The point midway between them is known as the neutral point. The end of a compass needle which points to the north is termed the north pole while the opposite end is called the south pole. The north pole of a magnet is generally marked in some manner to distinguish it from the south pole.

Magnets are of two kinds, permanent and temporary. Permanent magnets are either bar or horseshoe, the names arising from their shape. A permanent magnet must be a piece of steel which has been magnetized and which retains its magnetism indefinitely. A temporary magnet may be a piece of iron or steel, either under the influence of a permanent steel magnet or temporarily magnetized by an electric current (electro-magnet).

There is a distinction between substances which are magnetic and those which are non-magnetic. Iron and steel are the only sub-

stances which manifest magnetic properties to any great extent. Two other metals, nickel and cobalt, are very slightly magnetic. For practical purposes all other substances, such as copper, lead, gold, brass, bronze, wood, rubber, glass, etc., cannot be magnetized and are therefore non-magnetic. However, magnetic forces will flow through these substances.

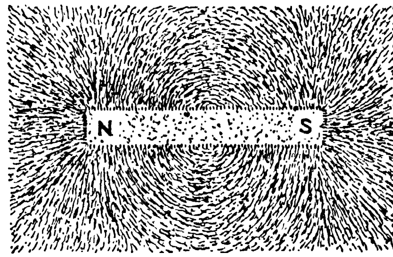


Fig. 76 — Field surrounding a bar magnet

A distinction must also be made between magnets and magnetic substances. A magnet attracts only at its poles, each of which possesses opposite properties. A piece of iron will be attracted by a magnet no matter what part of it is approached to the magnet; but it does not possess fixed poles or a neutral point, while a magnet always has two poles and a neutral point.

Surrounding any magnet there exists what is known as the magnetic field. It is invisible and in fact is not perceptible to any of the senses. That it does exist can be proved by placing a piece of paper over the magnet and sifting iron filings over it. The magnetic force which permeates the space immediately surrounding the magnet causes the filings to arrange themselves in a certain definite manner indicating the nature of the force, its direction, and distribution. The magnetic force is not the same at all distances but decreases as the distance from the magnet increases. Fig. 76 shows the magnetic field existing about a bar magnet, while Fig. 77 shows the magnetic field of a horseshoe magnet.

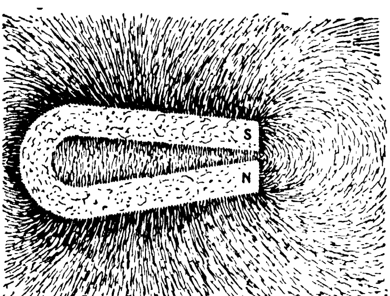


Fig. 77 — Field surrounding a horseshoe magnet

It is assumed that the magnetic lines of force (Figs. 76 and 77) emanate from the north pole of the magnet, pass through the surrounding medium, re-enter at the south pole and complete the circuit by passing from the south to the north pole through the magnet itself. Every line of magnetic force must have a complete circuit; hence, it is impossible to have a magnet with only one pole. Magnetic lines of force complete their circuits independently and never

cut across or merge into each other. The fact that all the lines of force pass through the magnet itself accounts for the concentration of magnetic force at the poles.

Lines of magnetic force will pass through some substances more readily than through others. When a piece of iron is placed in a magnetic field the lines of force are bent out of their natural paths and pass through the iron. There are now more lines of force passing through the space occupied by the iron than when this space was occupied by air only. The property of any substance for conducting magnetic lines of force is termed its "permeability."

As shown in Fig. 78, a bar of soft iron placed in a magnetic field will cause distortion of the lines of force, many of which will pass through the iron. Magnetic lines of force always take the path of

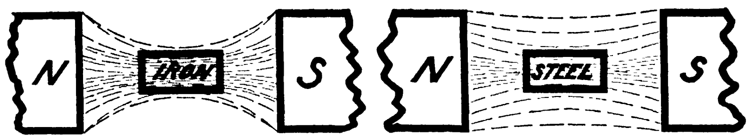


Fig. 78 — Permeabilities compared

least resistance. If the piece of iron is arranged free to move in the field, it will take up such a position as to accommodate through itself the greatest possible number of lines of force. If, instead of being a magnetic body, it is a magnet, it will move under the influence of the magnetic field in which it is placed, not only so as to accommodate through itself the lines of force of the field but also in a particular direction so that its lines will be in the same direction as those of the field. Thus a magnet always tends to place itself so that lines of magnetic force enter its south pole and leave at its north pole.

Magnetic substances have the greatest permeabilities but the permeability of every magnetic substance is different. If a piece of steel is substituted for the soft iron (Fig. 78), fewer lines of force will pass through the same space, thus showing that the conducting power of soft iron is greater than that of steel. The permeability of iron may be as high as two thousand times that of air, that is, two thousand times as many lines of force will pass through the same space when occupied by iron as when occupied by air.

The path taken by magnetic lines of force in passing from any pole of the magnet through the surrounding medium and back to the same pole again is known as a magnetic circuit. The simple magnetic circuit is composed of a magnetic substance throughout its entire length, as, for example, a magnetized iron ring or a horseshoe

magnet with a keeper across its poles. A compound magnetic circuit is one in which the lines of force must pass through both magnetic and non-magnetic substances, as, for example, a horseshoe magnet without its keeper.

If two bar magnets are placed side by side and the resultant magnetic field is obtained by sifting iron filings on a paper covering

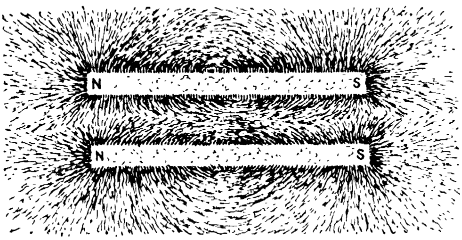


Fig. 79 — Field resulting with like poles adjacent

them, it will be seen that the arrangement of the lines of force will depend upon whether opposite poles or like poles are adjacent.

When like poles are adjacent (Fig. 79), the lines of force striking against each other are distorted from their natural paths and compressed into a small space. This causes the magnets to be mutually repelled, since the lines of force try to return to the regular positions that they normally occupy, as shown in Fig. 76.

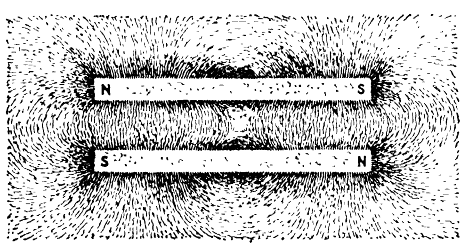


Fig. 80 — Field resulting with unlike poles adjacent

If unlike poles are adjacent (Fig. 80), the lines of force flowing from the north pole of each will enter the adjacent south pole, since the steel offers a better path than air because of its greater permeability. This causes the lines of force to be stretched out of the regular positions; and mutual attraction results, because the lines of force tend to return to their normal positions. Thus it is seen that like poles of magnets repel while unlike poles attract, both of which effects are the direct result of distortion of the magnetic field.

It is the same phenomenon that causes a piece of iron to be attracted by a magnet. When a piece of iron or steel is near enough to a magnet to be in its magnetic field, some of the lines of force stretch out and pass through the piece of iron. This causes distortion of the magnetic field and results in the iron or steel being drawn to the nearest pole of the magnet (Fig. 81). While this is taking place the flow of lines of force through the piece of iron or steel

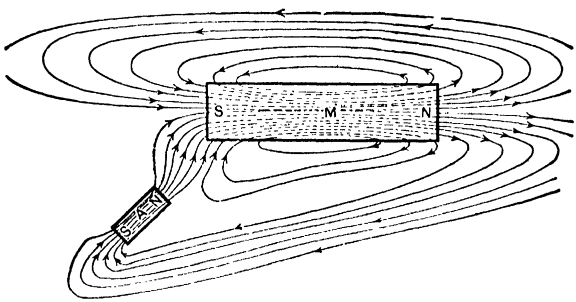


Fig. 81 — How magnet attracts iron

causes it to become a temporary magnet. When any body is magnetized by the influence of a magnet, it is said to be due to magnetic induction. Contact between the inducing magnet and the body magnetized is not necessary; magnetization can take place through all non-magnetic substances, whether they are solids, liquids, or gases.

From the foregoing, the following laws of magnets have been deduced:

1. Unlike poles of magnets are mutually attracted.
2. Like poles of magnets are mutually repelled.
3. Magnetic lines of force always take the path of least resistance.

Polarity. — If the polarity of a magnet is unknown it can be determined by using a compass needle or other small magnet of known polarity in accordance with the laws just stated.

The molecular theory of magnetism explains why a piece of iron or steel can be magnetized. All substances are composed of minute particles which are called molecules. The molecules composing iron or steel are each individual magnets. When the iron or steel is not magnetized, the molecules arrange themselves promiscuously in the material; but, according to the law of attraction between unlike poles, local magnetic circuits are formed internally and there is no resulting external magnetism. Possible positions in which the

particles composing a magnetic substance may arrange themselves when there is no external magnetism are shown at the left in Fig. 82. It must be remembered that there may be as many as a million or more variously arranged magnetic circuits in even a very small piece of iron or steel. When the piece of iron or steel is placed in a magnetic field, each little magnetized particle tends to place itself so that its axis is parallel to the direction of the magnetic field, with its north pole pointing so that the lines of force must pass out at that end. This causes the closed magnetic circuits to be broken up and the particles to arrange themselves parallel to each other with their north poles all pointing in the same direction, as shown at the right in Fig. 82. The iron or steel now manifests external magnetism

Fig. 82 — Arrangement of molecules in a magnetic substance

and will continue to do so as long as the molecules stay in this arrangement.

When under the influence of a strong magnetic field, soft iron possesses greater attractive force than steel. When the magnetic field is removed, however, the steel possesses attractive properties far superior to that of the iron and retains them permanently with little loss. The soft iron remains very slightly magnetized with what is commonly known as "residual magnetism." This difference is easily explained by the molecular theory of magnetism. The molecules of iron and steel offer considerable resistance to the force tending to turn them on their axes, the resistance of the steel molecules being much greater. It is difficult to turn them around, but once being turned around it is equally difficult for them to return to their original positions, because of the friction between themselves; hence the resulting permanent magnetism in steel. On the other hand, the molecules of soft iron turn very readily under the influence of a magnetic field but resume their original positions when the magnetic field is removed as the friction between the molecules is much less, accounting for the temporary magnetism in iron. Not all of the molecules regain their exact original positions, as is shown by the slight trace of magnetism always found in any piece of iron after having been magnetized.

It is impossible to see the molecules of iron or steel changing their relative positions under the influence of magnetism but experiment has shown this theory to be correct. It is assumed that the mole-

cules composing the iron or steel are regularly disposed, which necessarily has to be the case. When local magnetic circuits are formed, magnetization turns the molecules on their axes until they are arranged symmetrically. When they have all been turned around, the bar is said to be saturated or completely magnetized. No matter how much additional magnetic force is available, the magnetism of the bar cannot be further influenced.

Since magnetism depends upon the arrangement of the molecules in the magnetic substance, their displacement will cause the partial or total loss of external magnetism. Any vibration tends to destroy permanent magnetism. For this reason, permanent steel magnets

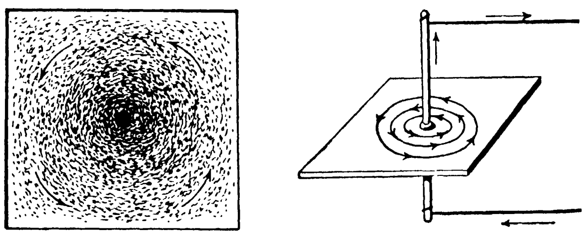


Fig. 83 — Field about current-carrying conductor

should never be dropped or struck. Slight shocks are sufficient to demagnetize soft iron; steel retains with tenacity the properties of a magnet, but its magnetic strength is impaired by shocks and will be entirely destroyed by a sufficient vibration.

Vibration may be produced in a substance by heat, which causes the molecules to become more widely separated and reduces the internal friction between them. When sufficient heat is applied to a magnet, it will entirely lose its magnetism because its molecules have become disarranged by the resulting vibration. For this reason, heat should never be applied to permanent magnets.

When current flows through a conductor, an electromagnetic field is set up about it. Every wire carrying a current possesses this magnetic field, as can be proved by bringing a compass needle near the wire. The magnetic field of the wire acts on the magnetic field of the compass needle, causing it to be deflected. If a wire through which current is flowing is passed through paper upon which iron filings are sifted, they will arrange themselves in concentric circles with the wire at the center, as shown in Fig. 83. Thus it is seen that the magnetic field around a straight wire carrying a current consists of a cylindrical whirl of circular lines, their intensity decreasing as the distance from the wire increases, as shown in Fig. 83.

As is true of all lines of magnetic force, these magnetic whirls do not merge, cross, or cut each other, but complete their circuits independently around the wire as shown in Fig. 84.

The direction of the magnetic whirls about the wire depends upon the direction in which the current is flowing through it. If the

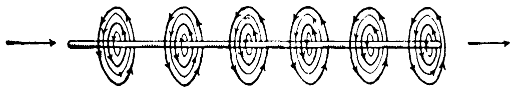


Fig. 84 Magnetic whirls

thumb of the right hand is placed along the wire in the direction in which the current is flowing, the curved fingers will indicate the direction of the magnetic whirls about the wire. This may be checked by placing a compass needle near the wire to show the direction of the lines of force by its deflection.

If a wire is arranged as shown in Fig. 85, so that it describes a half-circle above the cardboard, its magnetic field can be shown by sifting iron filings on the cardboard. When current is passing through the wire, the iron filings arrange themselves circularly around the wire. It is seen that the magnetic lines of force pass down through the center of the loop, as can be confirmed by applying the right-hand rule.

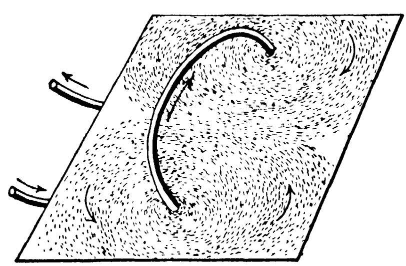


Fig. 85 — Direction of field through loop of wire

If a wire is bent into a circular loop and current sent through it (Fig. 86), all the magnetic whirls about the wire will pass in through one side of the loop and out the other. If a compass needle is brought near the loop, it will be attracted by the magnetic field of the loop just as it would be by a bar magnet. This is due to the fact that the side of the loop from which the magnetic whirls emerge acts as the north pole, while the other side manifests south polarity.

If a coil of wire is wound into a helix and current sent through it, the result will be as shown in Fig. 87. Magnetic whirls are set up about each turn of the helix; but, because the turns of wire are so near each other, the whirls join together instead of completing separate circuits, looping all the turns composing the helix and forming a continuous magnetic field. The total field is the sum of the magnetic lines of each individual turn, since it is the result of

the whirls about adjacent conductors joining together and the sum of all the turns constitutes the field or total number of lines of force passing through the coil. The field set up by the coil is shown in Fig. 87 and it will be seen that one end of the coil is the north pole

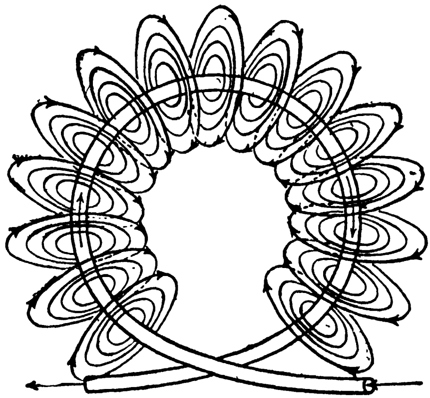


Fig. 86 — Whirls about loop of wire

while the other end is the south pole, just as was true of the two sides of the single loop of wire through which current was flowing. If the curved fingers of the right hand are placed about the coil of wire in the direction the current is flowing, the thumb will indicate the north pole of the coil.

When a great many turns of wire are wound on a wooden or brass spool similar to the winding of a spool of thread, the resulting coil is called a "solenoid."

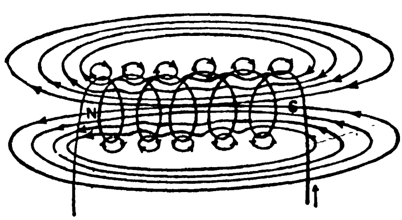


Fig. 87 — Field about helix

An iron or steel bar inserted in a solenoid through which current is flowing is a much better conductor of the magnetic lines of force inside the solenoid than is the air, so that the strength or attractive force of the solenoid is materially increased, though the magnetizing current is the same as before. An iron core introduced into a solenoid carrying a current becomes strongly magnetized and is called an electro-magnet (Fig. 88). The direction of the lines of force through the iron core of the solenoid is the same as their natural direction through the solenoid alone, so that the laws of polarity of the solenoid hold for the electro-magnet. The molecular theory of magnetism explains how magnetism is produced in the iron bar by

passing current around it. The solenoid's magnetic field acts upon the molecules composing the iron bar, causing them to arrange themselves parallel and producing an external field about the core. The magnetic field set up by the current simply makes actual the latent magnetism of the iron. This molecular action also accounts for the permanent magnetism produced in a piece of steel that has been inserted in a solenoid, since the friction between the molecules prevents many of them from resuming their original positions.

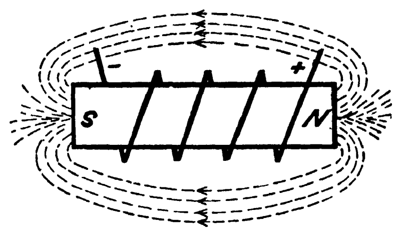


Fig. 88 — Electro-magnet

If a coil of wire is wound around an iron ring and current is sent through the wire, lines of magnetic force will flow around through the iron ring. If a small air gap is made in the ring by sawing out a section, a compound circuit is formed and lines of force are compelled to pass through the air gap to complete their circuit, so that north and south poles are produced. The lines of force through the iron part of the circuit are not nearly so dense as before, because the resistance of the circuit has been increased by introducing an air gap. If the removed section of the ring is now replaced and the ring is covered with iron filings while it is magnetized, a great many filings will be attracted at the two joints. This illustrates magnetic leakage. When magnetic leakage takes place with permanent magnets, their strength is impaired. This should be guarded against, especially when dismounting magnets.

CHAPTER XV

ELEMENTARY ELECTRICITY

The term " electricity " has been applied to an invisible force known largely by the effect it produces. Little is known of its exact nature, although the laws governing it are clearly understood and defined. These can best be explained by comparing its flow to that of water, to which it is similar. However, it must be remembered that electricity is not a liquid and is only compared with water to understand better its flow.

Fig. 89 shows two tanks *A* and *B* at the same level (*A* being filled with water) connected by a pipe in which is placed a valve. When the valve is opened slightly, the water will flow slowly from *A* into *B* until the level of water in both tanks is the same. If the

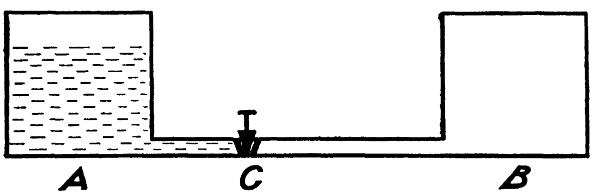


Fig. 89 — Water analogy to flow of electrical current

valve had been opened wider, the flow of water would have been faster, because a larger opening offers less resistance to flow. Had air been pumped into the top of tank *A* until a high pressure was obtained, the flow of water through the pipe into tank *B* would have been still faster. Although the rate at which the water flows from tank *A* into tank *B* may vary, the quantity that flows is independent of the rate and depends only upon the difference in pressure between the two tanks. It is seen that pressure is required to cause water to flow and that the rate of flow can be increased by reducing the resistance to its passage or by increasing the pressure.

In Fig. 90 the two terminals *A* and *B* of the dry cell are connected by a wire through the switch *C*. This arrangement may be compared to the two tanks connected by a pipe; the positive terminal *A* corresponding to the full tank, the negative terminal *B* corresponding to the empty tank, the wire to the pipe, and the switch *C*

to the valve. When the switch is closed, current flows from A to B through the wire. The water flows from tank A to tank B because there is greater pressure at A than at B. Current flows from terminal A to terminal B because there is greater electrical pressure at A than at B.

Water pressure is usually measured in pounds per square inch; electrical pressure is measured in volts. The amount of water that flows may be measured in gallons or in barrels; the amount of current that flows is measured in amperes. The smaller or longer the pipe, the less will be the water flowing through it, because of the increased resistance; similarly, the smaller or longer the wire, the less will be the current flowing through it, because of the increased resistance, and this electrical resistance is measured in ohms.

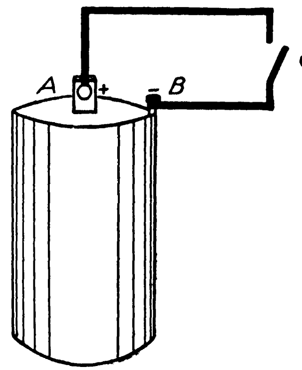


Fig. 90 — Simple electric circuit

The pound and the gallon are definite units of pressure and quantity, both of which are familiar. Years ago, in order to decide upon similar units for measuring electricity, a committee was appointed, made up of prominent scientists of the time. Dr. Ohm was chairman of this committee, which met in his laboratory to decide the units by which electrical pressure, current, and resistance should be measured.

It was decided that the amount of pressure given by a certain cell should be the standard unit to which all other electrical pressure should be compared. The cell chosen was the voltaic cell, and the amount of pressure this cell gave was named the " volt." A six-volt battery is one having six times the pressure of the voltaic cell.

To obtain the unit of resistance, it was decided to take a certain conductor and call its resistance the standard to which all others should be compared. The one chosen was a tube of mercury of definite size and length, and the amount of its resistance to the flow of current through it was named the " ohm." A conductor which has three ohms resistance is one that offers three times as much resistance to the flow of current as the original tube of mercury.

To obtain the unit of current, it was decided to take this cell giving one volt pressure and connect its terminals with the tube of mercury, and the amount of current that flowed was named the " ampere." A circuit which has 10 amp flowing through it is one

in which the current is 10 times as great as that caused to flow by a pressure of one volt through one ohm resistance.

Referring to Fig. 89, if the pressure is increased and the pipe size and length remain the same, more water will flow; the same is true of electricity. If the pressure (voltage) is increased, more current (amperes) will flow through the circuit, provided the resistance is not changed. If the pressure remains the same but the size of the valve opening is made smaller or the pipe decreased in size or increased in length, less water will flow; the same is true in electric circuits. If the pressure (voltage) remains the same and the wire is decreased in size or increased in length, increasing the resistance (ohms), less current (amperes) will flow.

By experiment it has been found that the flow of electricity always depends upon the pressure and resistance of the circuit, and that definite laws govern the amount of change in the flow of electricity for a given change of either of these. The relation between electrical pressure, current, and resistance is known as Ohm's Law, and is as follows:

1. The strength of current flowing in any circuit is equal to the pressure in volts divided by the resistance of the circuit in ohms.

2. The strength of current in any circuit increases or decreases directly as the pressure increases or decreases when the resistance is constant. With a constant pressure, the current increases as the resistance is decreased and decreases as the resistance is increased.

$$\text{Current} = \frac{\text{Pressure}}{\text{Resistance}}$$

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$$

$$\text{or, } I = \frac{E}{R}$$

Problem 1. — With a six-volt battery and a circuit of two ohms resistance, how many amperes of current will flow in the circuit?

$$I = \frac{E}{R} = \frac{6}{2} = 3 \text{ amp}$$

Problem 2. — If the voltage is increased to 12 volts and the resistance is the same, how many amperes of current will flow?

$$I = \frac{E}{R} = \frac{12}{2} = 6 \text{ amp}$$

This shows how the current increases as the voltage increases.

Problem 3. — If the resistance is increased to 3 ohms and the voltage is the same, how many amperes of current will flow?

$$I = \frac{E}{R} = \frac{6}{3} = 2 \text{ amp}$$

Showing how the current decreases as the resistance increases.

If the two tanks *A* and *B* (Fig. 89) are connected by a solid rod, no water can flow; a hollow rod or pipe is necessary to permit water to pass through it. If the terminals *A* and *B* (Fig. 90) of the dry cell were connected by a glass rod, no current could flow; a metal rod or wire is necessary to permit electric current to pass through it. For this reason metals and other substances that electricity flows through easily, because of their low resistance, are called **conductors.**

To retain water, a pipe must be made of strong enough material to withstand the pressure exerted by the water passing through it. Similarly, to retain the current passing through it, a wire must be surrounded by some material through which current cannot pass. Materials which offer considerable resistance to the passage of current through them are called non-conductors or **insulators.**

All conductors do not conduct electricity equally well, since the resistance of every substance is different. Silver, copper, aluminum, steel, and iron are all good conductors and offer but little resistance to the flow of current. Materials such as glass, porcelain, rubber, silk, cotton, fiber, wood, and air offer a great deal of resistance to the flow of current and are classed as insulators. As in the case of conductors, all insulators do not resist the flow of current equally well.

Ohm's Law states that the pressure in an electric circuit determines the amount of current that will flow. In other words, pressure can overcome resistance and force current to flow. For this reason, an insulator of much higher resistance must be used when the pressure is high in a circuit than would be necessary if the pressure were low.

For electric current to flow, a path consisting of conductors must be provided. A break in the circuit will cause the current to cease flowing, and it is said to be " open circuited."

The common circuits used in ignition, lighting, and starting work are series and parallel.

Series Circuit. — When electric lamps are connected as shown in Fig. 91 they are said to be in series, because the current flows through each lamp to the next succeeding one, returning from the last one to the battery. In a circuit of this kind, the resistance in-

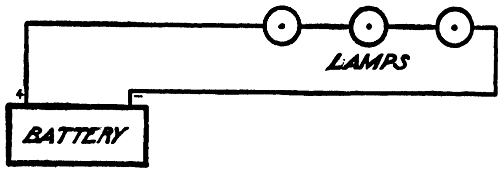


Fig. 91 — Series circuit

creases as the number of lamps is increased, the current decreasing if the pressure remains the same.

Parallel Circuits. — When electric lamps are connected as shown in Fig. 92 they are said to be connected in parallel. All the current in this case does not have to flow through every lamp, but part

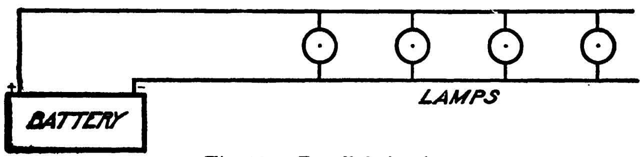


Fig. 92 — Parallel circuit

of it flows through each and back to the battery through the common return wire.

If two tanks *A* and *B* are connected as shown in Fig. 93 and valve *C* is opened, a certain amount of water will flow between them. If valve *D* also is opened, more water will flow because another path has been opened, reducing the total resistance. If valve *E* also is opened, a still greater quantity of water will flow.

This is analogous to the arrangement shown in Fig. 92. As more lamps are added, the total resistance of the circuit is reduced and more current flows if the pressure remains the same.

Lights on cars are connected in parallel, so that turning on additional lights will not require a change of voltage. Also, the burning out of one light will not put out any of the others.

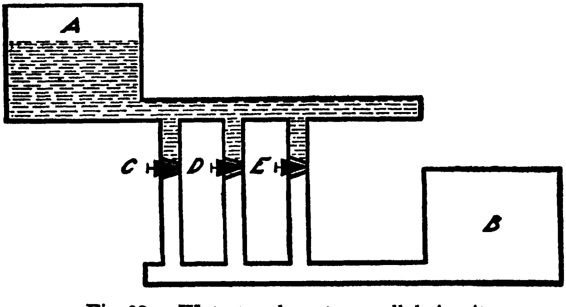


Fig. 93 — Water analogy to parallel circuit

CHAPTER XVI

INDUCTION

When electricity is produced by chemical means, the voltage is low and therefore is not suitable for ignition systems unless the voltage is increased in some manner. High voltages are obtained by electro-magnetic induction, and this method of obtaining higher voltages is applied to ignition systems. To understand ignition thoroughly it is necessary to study the elementary principles underlying induction.

Comparatively little is known about the exact nature of magnetism and electricity, but much has been discovered concerning the relation existing between them. It has been shown that whenever

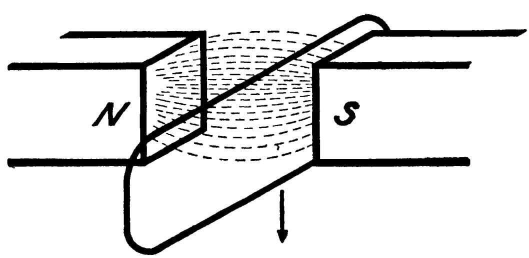


Fig. 94 — Electro-magnetic induction

there is a current of electricity flowing there is always a magnetic field present. This magnetic field lasts as long as the current continues to flow, showing that there is a definite relation existing between magnetism and electricity. Since electricity produces magnetism, it is reasonable to expect magnetism to produce electricity, and it has been found by experiment that this is true.

If a magnetic field is present and a loop of wire is moved so as to cut the magnetic lines of force (Fig. 94), a current is caused to flow through the conductor. Currents generated in this way are known as induced currents, and the phenomenon is termed electro-magnetic induction. The same result is obtained if the conductor is kept stationary and the magnetic lines of force are moved so as to be cut by the conductor.

The direction of the flow of the induced current in the conductor will depend upon the direction of the lines of force and the direction

in which the magnetic field is cut. A simple method of determining this, when the direction of motion and direction of the lines of force are known, is by the means of the right-hand rule. Place the thumb and the first and second fingers of the right hand all at right angles to each other (Fig. 95) and in such relation to the conductor that the first finger points in the direction of the lines of force and the thumb in the direction of motion. The second finger will then indicate the direction of the induced current. Applying this rule to Fig. 95 in which the wire is being moved upward and the lines of force flow from the north pole as indicated, the current is found to flow through the conductor as indicated by the arrow.

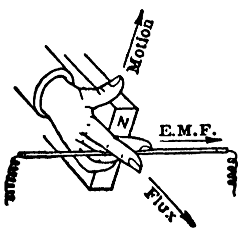


Fig. 95 —Right-hand rule

The strength of the induced voltage in a conductor when it is cutting lines of force is proportional to the rate at which the lines of force are cut. If a circuit of several turns of wire is substituted for the single loop used in Fig. 94, the induced voltage will be greater. This results because each loop now cuts as many lines of force as were cut by a single loop, increasing the total number of lines of force cut. If the strength of the magnet is increased, it will cause more lines of force to be set up so that the same number of turns moving through the field would cut a greater number of lines of force, thus causing an induced current of higher voltage. The induced voltage will, therefore, depend upon the following factors:

1. The strength of the magnetic field
2. The speed or rate of cutting lines of force
3. The number of turns of wire cutting the lines of force.

Self Induction. — If a coil of wire is placed about a core of soft iron and current is sent through the coil, magnetic lines of force will be set up. If the circuit is broken by opening the switch *A* (Fig. 96), the current ceases to flow and the magnetic field will collapse. In collapsing, the lines of force cut the winding of the coil, inducing current in the coil. This is called self induction. Self induction is defined as " the cutting of a wire or coil by the lines of force set up by the current flowing through it." Applying the right-hand rule, it will be seen that the direction of flow of the induced current is the same as that of the flow of the interrupted current. When applying the right-hand rule, do not take the motion of the lines of

force as the direction of motion, but take the equivalent motion of the conductor.

The induced voltage will be much higher than that of the current which set up the magnetic field. When the switch is opened, this high induced voltage causes an arcing between the separating con-

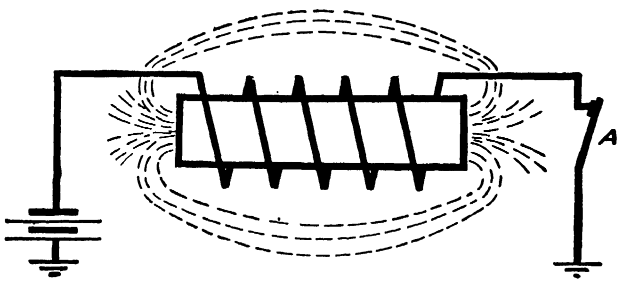


Fig. 96 — Self induction

tacts. When self induction is present in an ignition system, the induced voltage is approximately 200 volts, which is not sufficiently high to jump a fixed air gap of any appreciable size but will cause a following arc between separating points.

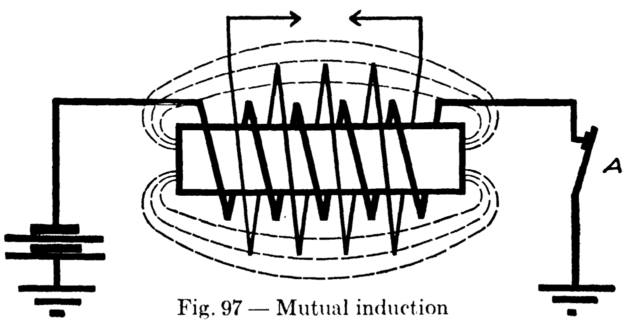


Fig. 97 — Mutual induction

When the circuit is made, the magnetic field in building up also cuts the winding. By applying the right-hand rule it will be seen that the induced current opposes the flow of the current setting up the field. This is termed counter electro-motive-force and its opposition to the increasing current in the coil causes the field to build up very slowly.

Mutual Induction. — If two coils of wire are placed about an iron core and current is caused to flow through one of them (Fig. 97), a magnetic field will be built up about the core. The coil through which this current is caused to flow is known as the pri-

mary and the other coil is called the secondary. If the switch *A* is now suddenly opened, this magnetic field collapses and *both* windings are cut by lines of force. This causes currents to be induced in both the primary and secondary windings; that in the secondary is said to be mutually induced current. Mutual induction is defined as " the cutting of a wire by lines of force set up by current flowing through another wire or coil." *There is no electrical connection between the primary and secondary windings.* By applying the right-hand rule it will be seen that the induced current in the secondary flows in the opposite direction to the inducing current in the primary when the primary circuit is made, and in the same direction when the primary circuit is broken.

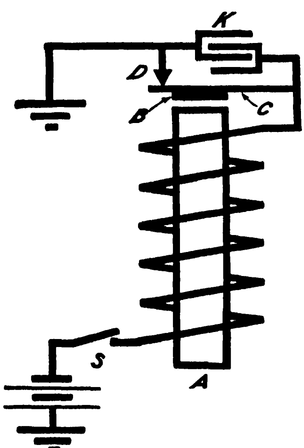


Fig. 98 — Simple vibrator

When the primary circuit is made, a counter emf results, which tends to oppose the building up of the field. The mutually induced current in the secondary sets up a field which tends to strengthen this counter emf, further retarding the building up of the magnetic field. Thus the current flowing in the primary has to overcome the counter emf due to the induced current. Hence the rate at which the field builds up is slow and the resulting voltage in the secondary will be correspondingly low. When the primary circuit is broken, however, there is no counter emf in the primary; the result is a sudden collapse of the field and a consequently high voltage is induced in the secondary.

When high voltages are desired, they can be obtained by mutual induction, employing a much greater number of turns of wire in the secondary winding than in the primary. The voltages in the primary and secondary windings vary directly as the number of turns of wire in each, while the current varies inversely as the number of turns of wire. For this reason, fine wire is used for the secondary windings and much heavier wire for the primary.

Fig. 98 shows a simple vibrator which is used for making and breaking a circuit. It consists of a coil wound about a soft iron core *A;* opposite one end of this core is placed a small piece of soft iron *B*, attached to a spring *C*. An adjusting screw *D* is in contact with the spring when in its normal position.

One side of the battery is grounded while the other is connected

through the switch S to the coil; the other end of the coil is attached to the spring C, and the screw D is grounded.

When the switch is closed, a magnetic field is set up, magnetizing the core. This attracts the iron B, breaking the circuit at D. This causes the core to be demagnetized; and the spring C returns to its normal position, again closing the circuit. This operation will be repeated over and over as long as the switch S is closed. Thus the circuit is automatically made and broken.

When the circuit is broken, the collapse of the magnetic field induces a current in the winding. The voltage of this self-induced current is sufficient to cause an arc to follow the separating points at D each time the current is broken. The arcing burns and pits the contact points, increasing the resistance of the circuit. To prevent this, a condenser K is connected in parallel with the contact points, as shown in Fig. 98. When the circuit is broken, the flow of induced current passes into the condenser, charging it. This momentarily diverts the flow of current from the contact points, allowing them to separate sufficiently to prevent a following arc.

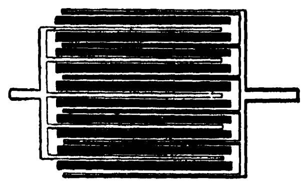


Fig. 99 — Condenser

A condenser is usually constructed of sheets of silver, tin, or lead foil, alternate sheets being connected to common terminals and separated from each other by some insulating material such as mica or specially treated paper (Fig. 99).

The capacity of a condenser depends upon the total area of the plates and the distances these plates are separated by the insulating material. Condensers used in ignition systems must be of sufficient capacity. This is governed by the amount of self-induced current in the circuit.

CHAPTER XVII

THE BATTERY AND THE GENERATOR

The electrical current needed to produce the spark which ignites the fuel; to motivate the self-starter; to operate the lighting system; and to run the radio, heater, and many other units of the modern automobile is produced by a storage battery acting in conjunction with a generator. The battery must furnish all the current for starting and for lighting when the motor is not running and the generator is not in operation. The battery is kept charged automatically by the generator.

Battery. — The battery consists of a series of storage cells in which chemical energy is changed into electrical energy. When the battery is being recharged, this process is reversed. Description of a simple primary cell will indicate how this transformation is brought about, the only difference between a storage and a simple primary cell being that the storage cell can be recharged after having discharged itself.

A simple primary cell is made by placing two dissimilar metals in an acid or alkaline solution. Fig. 100 shows a plate of zinc and a plate of copper placed in a glass jar containing a solution of sulfuric acid. If the plates are connected by a piece of wire, a chemical reaction takes place between the zinc plate and the acid, causing the zinc to be gradually wasted away. This causes the terminal at the copper plate to be positively charged, resulting in a flow of current from the terminal at the copper plate through the wire to the terminal at the zinc plate. This action continues as long as any of the zinc is left, or until the acid has become so weak that its power to attack the zinc is exhausted. If the connection between the plates is broken at any time, the chemical reaction stops and will continue only when the circuit is made again. This simplest form of chemical cell illustrates the fundamental principle underlying the operation of the chemically produced electrical current in modern storage battery cells — as well as in all other cells producing electrical current chemically.

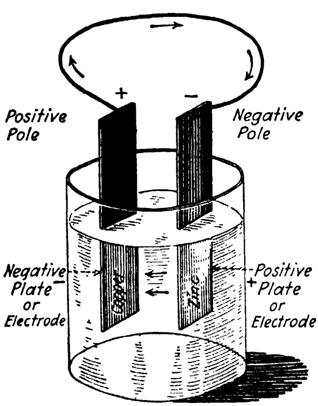


Fig. 100 — Simple electric cell

In the cell of the modern storage battery the dissimilar plates (called electrodes) consist of perforated grids into which lead or lead peroxide has been pressed, as shown in Fig. 101. The solution of sulfuric acid is known as an electrolyte. The grids are made of an alloy of lead and antimony, which makes them resistant to electro-chemical corrosion, and gives them strength and rigidity. The group of plates connected to the positive terminal of the cell consists of grids filled with a paste of lead peroxide, characterized by its brown color. The group of plates connected to the negative terminal of the cell consists of grids filled with metallic lead of a spongy nature. This lead is dull gray in color.

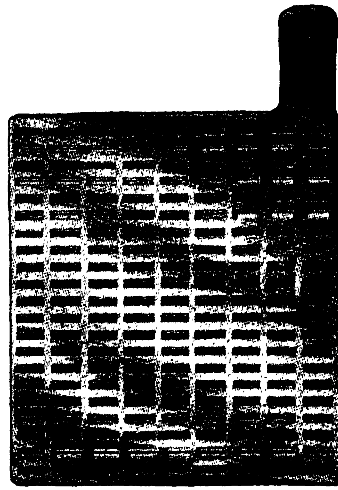


Fig. 101 — Storage-battery grid

These plates are arranged in the cell so that the positive and negative plates alternate. Between the plates are placed separators to prevent the positive and negative plates from coming into contact. The separators must be porous to allow the solution to pass through freely. They are usually made of specially treated wood or hard rubber. The jar or container in which the plates are placed is usually made of hard rubber which is not affected by the acid. The assembly of plates and separators, Fig. 102, is placed in this jar and a solution of sulfuric acid and distilled water is added until the level of the liquid in the jar is about 3/8 in. over the tops of the plates. The cell is sealed by a cover of hard rubber, through which the positive and negative terminals project (Fig. 103). A filler cap, incorporating an air vent for the escape of gas, is provided. Through this filler opening, distilled water is also added to keep the plates covered.

One type of filler cap has a condensing chamber in which gases from the electrolyte will be condensed and returned to the cell. Another type is placed on a vent next to the filler hole when distilled water is put in. This creates an air seal which prevents overfilling the cell.

In modern passenger cars, three storage cells are connected in series to form batteries which will give higher voltage than a single cell. The voltage of a cell is usually considered to be two volts, since this is the average value. All batteries of modern passenger cars are three-cell, six-volt batteries.

If greater amperage is desired, the number of plates is increased, since the amperage depends on the area of plate surface in contact with the acid. About 1 sq ft of plate surface must be in contact to produce 40–60 amperes (amp). Passenger-car batteries have 11, 13, 15, 17, 19, or 21 plates. There is always one more negative plate than positive plate.

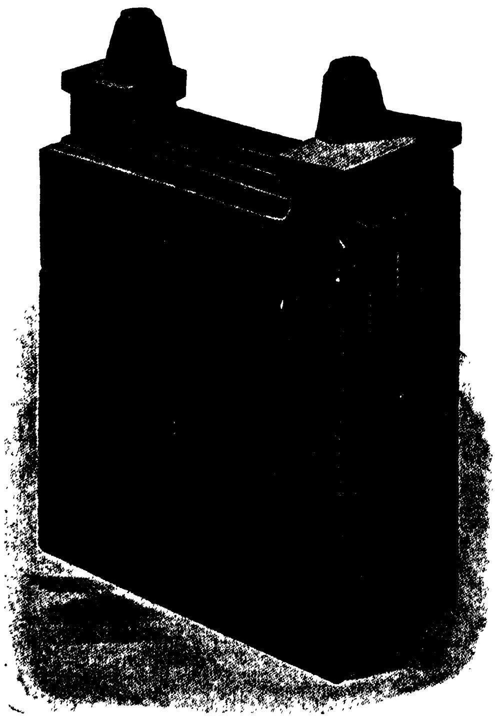


Fig. 102 — Plate assembly

The rating of storage batteries is usually given in volts and ampere hours. An ampere-hour (amp-hr) is the quantity of electricity delivered in 1 hour (hr) by a current of 1 amp strength. If 15 amp is the rate of discharge at which a given battery is rated, a 6 volt 120 amp-hr battery is one having three cells connected in series and discharging 15 amp of current for 8 hr.

The expected 8-hr life of such a battery will be reduced more than proportionately, however, if the battery is discharged at a rate in excess of 15 amp per hour during the 8-hr period. If, for example, the battery were to be discharged at the rate of 20 amp per hr, it would not last for 6 hr.

Similarly, if the battery be discharged at less than 15 amp per hr, its life will be *increased* more than proportionately. Should it be discharged at 5 amp per hr, in other words, it probably would last for more than 24 hr. Commercial passenger-car batteries are generally rated in ampere hours on a 20-hr basis. These batteries vary in capacity from 65–135 amp-hr when discharged in 20 hr, depending on their design and number of plates.

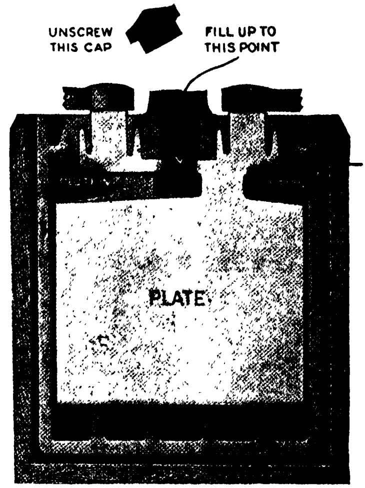


Fig. 103 — Cross-section through storage cell

The chemical reaction which takes place when a storage battery is discharging is as follows: The sulfuric acid (H_2SO_4) is broken up into two parts, H_2 and SO_4. The hydrogen is liberated at the lead peroxide plates (PbO_2), reducing them to lead oxide (PbO), which combines with parts of the sulfuric acid to form lead sulfate ($PbSO_4$) and water (H_2O). The SO_4 is liberated at the spongy lead plates (Pb) and combines with them to form lead sulfate ($PbSO_4$). During this process, the electrolyte grows less concentrated because of the absorption of SO_4 by the spongy lead plates.

When the battery is being charged by passing current through it in the opposite direction, the chemical action just described is reversed. The lead sulfate on one plate is converted back to lead peroxide, the lead sulfate on the other plate is reduced to spongy lead, and the electrolyte (sulfuric-acid solution) becomes more dense because of the increased amount of sulfuric acid. Following is a tabulation of the chemical reaction which takes place in a storage battery while discharging and charging.

Charge				Discharge			
Lead Peroxide	Sulfuric Acid	Spongy Lead		Lead Sulfate	Water	Lead Sulfate	"Q"
PbO_2 +	$2H_2SO_4$ +	Pb	$\rightleftarrows$	$PbSO_4$ +	$2H_2O$ +	$PbSO_4$ +	"Q"
Positive	Electrolyte	Negative		Positive	Water	Negative	Energy

(The symbol " Q " represents electrical energy furnished by the chemical action in the cells of the battery.)

The storage battery is restored to normal condition by passing direct current through it from some outside source. This recharg-

ing process is the same as the charging process just described, the chemical reaction taking place upon discharge being reversed. It is erroneous to say that electricity is stored in a storage cell. The storage cell is a means of converting electrical energy into chemical energy during charge and chemical energy into electrical energy during discharge.

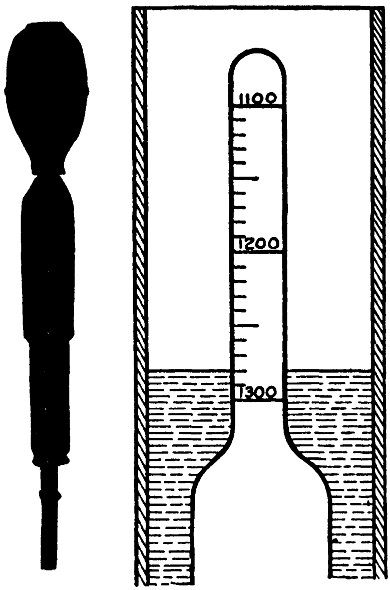


Fig. 104 — Hydrometer and syringe

During discharge, some of the sulfuric acid combines with the plates, causing the solution to have a greater proportion of water than sulfuric acid. This proportion increases as the discharging continues. The relative amounts of acid and water can be determined by reading the specific gravity of the solution. This is accomplished by the use of a hydrometer, contained in a syringe (Fig. 104). The electrolyte is drawn up into the syringe by the bulb; and the hydrometer float will sink to a greater or less extent according to the amount of sulfuric acid in the solution. If the hydrometer reads 1.280, it indicates that the liquid is 1.280 times as heavy as water. The scale of the hydrometer is read on the stem at the surface of the liquid when the hydrometer is floating in it, as shown in Fig. 104. All hydrometer readings are based on an electrolyte temperature of 80° F. A special thermometer is made, which, when immersed in the electrolyte, will record correctly the temperature of the electrolyte. To correct the specific gravity reading on the hydrometer for temperature subtract 0.001 specific gravity from the specific gravity reading for every 3° F below 80° F, and add 0.001 specific gravity for each 3° F above 80° F.

The readings of the hydrometer show the condition of the battery in accordance with the following table:

Reading	Condition
1.280–1.300	Full charge
1.250	¼ discharge
1.215	½ discharge
1.180	¾ discharge

During the chemical reaction which takes place in charging and discharging, heat is generated and causes loss of some of the water but not of sulfuric acid. When the solution in the cells gets below the top of the plates, more distilled water must be added. It is desirable to do this every week in summer and every two weeks in winter. In winter, water should be added just before using the car, so that the water will not freeze before combining with the sulfuric acid.

Specific Gravity	Freezing Point
1.150	5° F
1.180	Zero° F
1.215	−20° F
1.250	−60° F

When a battery is not to be used for two or three months, it should be given a fresh charge once a month and a thorough charge before being put back into service.

A hydrometer reading of less than 1.250 in colder climates, and of 1.180 in warmer climates indicates that recharging is needed if the best battery performance is to be obtained. If the water in the battery is allowed to get below the top of the plates and remain so for any length of time, the plates will buckle or warp and possibly puncture the separators which divide them. Such a puncture will cause a short circuit, which will soon ruin the battery. Even if lack of sufficient water should fail to result in puncture of the separators, it will impair the efficiency of both plates and separators, since the chemical reaction on the dry plates will make it all the harder to recharge the battery. It may possibly never be capable of becoming fully charged again.

Normal release of gases in the battery solution loosens the active material from the plates, and in time forms a sediment in the bottom of the cell. Loss of the active material from the plates constitutes the wearing out of the battery.

If, on a heavy ampere discharge tester, it is shown that one or more cells do not retain voltage, it is better to put in a new battery than to attempt to repair the poor cells. If one cell is bad, and the battery has been in use for a year or so, it follows that other cells are also liable to early failure. The heavy discharge test is the best way to determine battery condition, since under increasing ampere loads this test shows how the voltage stands up. If the voltage drops off rapidly, weakness is indicated in the particular cell being tested.

Battery cables and terminals should be checked, cleaned, and coated with light grease to prevent corrosion; and bolts should be tightened to give good electrical contact.

When installing a battery, it is important to ground the proper terminal, according to manufacturer's specifications.

The Generator. — The generator keeps the battery charged and, under some conditions, supplies current directly to points of use just as does the battery itself. The electrical output of a generator depends upon the mechanical energy supplied to drive it. Hence a generator is a piece of electrical apparatus for transforming mechanical energy into electrical energy in the form of induced electromotive force. This force causes electricity to flow through the external circuit (wiring outside the generator) from the positive terminal to the negative terminal, just as water flows from a higher to a lower level. In the internal circuit (wiring inside the generator) electricity flows from a lower to a higher voltage because of the induced electromotive force, just as water is pumped from a lower to a higher level.

Generators and electric motors are classified, according to their design and mechanical construction, as direct-current and alternating-current machines.

The current in the internal circuit is always alternating, but it can be changed to direct current in the external circuit by employing suitable moving contact pieces, which when assembled are called a commutator. Only direct-current machines can be used for generators and starting motors in motor vehicles, since a storage battery can be charged only with a direct current.

The simplest form of generator may be made by mounting a closed loop of wire on a shaft which can be revolved in the magnetic field existing between the north and south poles as shown in Fig. 105. If the loop is revolved as indicated by the arrow, the following will result: In the position shown by the dotted lines in Fig. 105*A*, there will be no induced electromotive force in the loop, since all the lines of force of the magnetic field thread through the loop. As the loop is turned in the direction of the arrow through one-fourth a revolution until it assumes a horizontal position, an electromotive force and electric current is set up in section *ab* of the loop in the direction of the arrow, along the solid line. In the same manner, the current passes along line *cd* in the direction of the arrow. The direction of the flow of current along the loop is determined by use of the right-hand rule (Fig. 95). The electromotive force along the loop is greatest in the center or horizontal position as indicated in the

diagram, and diminishes as it approaches the upper and lower limits, dropping to zero each time it passes the vertical position. At the end of the next half revolution from the horizontal position shown in Fig. 105*A*, when section *ab* of the loop is going up, and *cd* is going

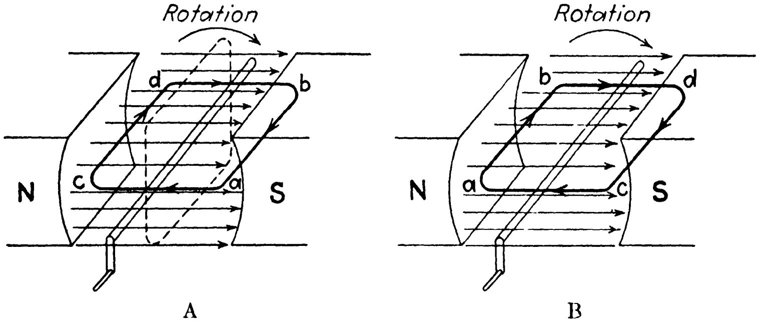


Fig. 105 — Principle of generator

down, the electromotive force induced in the loop will be in the opposite direction, as indicated in Fig. 105*B*. The current is reversed twice each revolution, an alternating current flowing around the loop.

To utilize the current flowing in a closed loop when it is rotated in a magnetic field, some mechanical device must be used to lead the current from the rotating loop so it will flow through an external circuit. This is accomplished by attaching the ends of the loop to metal contacts against which are held stationary pieces called brushes. If each brush is connected first with one contact piece or commutator bar and then the other commutator bar of the revolving loop and the change is made at the instant the current in each side of the loop is reversing, the current in the outside circuit will always flow in the same direction. This is accomplished by means of a commutator, made up of the moving parts previously mentioned.

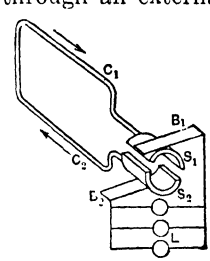


Fig. 106 — Simple commutator

The simplest form of commutator (Fig. 106) consists of a split ring, the segments S_1 and S_2 being insulated from each other and also from the shaft on which they and the loop are mounted. The brushes B_1 and B_2 rest on the commutator at diametrically opposite points, collecting the current and delivering it to the load L.

Assuming that the current in C_1 is flowing to the brush B_1, the current in C_2 must be flowing in the opposite direction or away from

brush B_2. Hence B_1 is positive and B_2 is negative. The brush B_1 bears on segment S_1 as long as the current in C_1 continues to flow in this direction. At the instant the current in C_1 starts to flow in the opposite direction, the segment S_1 leaves this brush and S_2 just makes contact with B_1. The current in C_2 has also reversed and now flows to segment S_2. Hence S_2 now delivers current to brush B_1, which

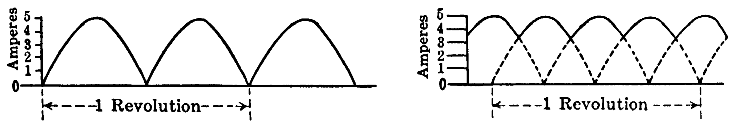


Fig. 107 — Graphic presentation of current in external circuit

still continues to be the positive brush. In the same way, brush B_2 is always the negative brush and the current delivered to the load always flows in the same direction.

When but a single loop of wire is used, the induced electromotive force will necessarily be low. By increasing the number of turns, the induced force is increased proportionately. With a single loop, the current delivered will not be steady although always in the same direction. The variations in the current flow are due to the change in the induced electromotive force from the maximum to zero as the loop is revolved. If another loop is placed at right angles to

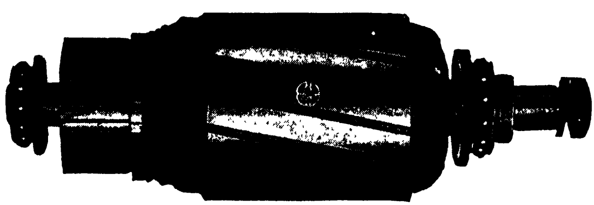


Fig. 108 — Curved slot armature

that shown in Fig. 106, the current flow in this loop will be the maximum when it is zero in the other loop. As the two loops are revolved, the current flow in one increases as that in the other decreases, giving a less pulsating current in the external circuit. Fig. 107 shows graphically the difference between the current delivered by a single loop and that delivered by two loops at right angles to each other. By equally spacing a great number of coils, a continuous current output and high electromotive force are obtained. The coils when mounted on a soft iron core constitute the armature. A typical armature is shown in Fig. 108. To obtain a more even flow of current, armatures have curved slots, as shown.

Air is circulated through the generator housing to keep the gen-

erator cool. The commutator is made up of copper segments, attached to each end of a coil or loop. The commutator bars are insulated from each other by inserts of mica or other suitable material.

In order to set up a strong magnetic field between the pole pieces, the field magnets of generators and motors are electromagnets. Part of the current generated in the armature is sent through shunt windings which consist of coils of wire on the pole pieces. Of course, no

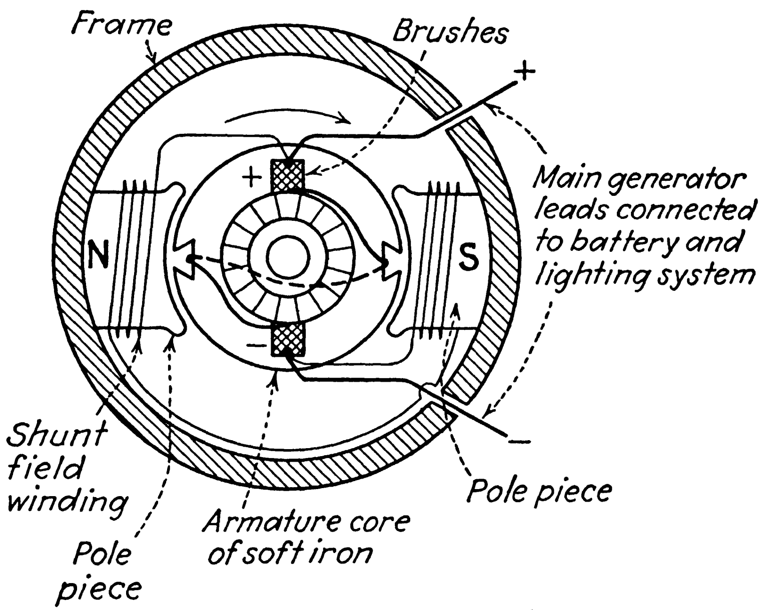


Fig. 109 — Simple two-pole shunt-wound generator

current would be generated in the armature at starting if there were not some magnetic field existing between the pole pieces. The soft iron pole pieces retain sufficient " residual " magnetism to set up a weak field, which in turn generates a weak current as the armature starts to turn in the field. This current flows through the field windings on the pole pieces, increasing the magnetic field, which in turn increases the generated current. In this way the machine " builds up " until the current output has reached its normal operating condition.

Although a shunt winding is usually used on the pole pieces of motor-vehicle generators as indicated above, series and compound windings could be used and were used in the past.

Fig. 109 is a diagram of a simple two-pole generator in which a shunt winding is used, one end of the shunt branching off at the posi-

tive main brush, passing around the pole pieces and returning to the negative main brush. Only about 10% of the generated current passes through the shunt winding, as the winding is a very fine wire. Enough current is carried, however, to build up the magnetic field between the pole pieces. Most of the current passes from the main positive brush through the generator system to the battery and other electric units, and returns through the ground to the negative main brush.

A generator such as the one just described would generate more current than the electrical system of the car could stand as the speed of the engine increased since, the faster the armature windings cut the magnetic field, the more current is generated. To protect the battery from overcharging and the lights from burning out, one of the following combinations of devices for regulating the output of the generator is used on the present-day generator systems:

1. Third-brush regulation of current output
2. Third brush in combination with vibrating voltage regulator
3. Vibrating current regulator
4. Vibrating voltage and current regulator

Before describing the details of these regulators, however, another device known as the generator cut-out, or cut-out relay, common to all generators, will be discussed.

Generator Cut-out. — The purpose of the cut-out is to protect the battery against discharge through the generator by disconnecting the battery from the generator when the engine is idling slowly or not running at all. Fig. 110 shows the path of current from the generator through the cut-out to the battery and return through ground to the generator. The action is as follows: When the engine is started and the generator output begins to build up, the cut-out contacts are open; the current passing through the coils on the cut-out is grounded at the end of the shunt coil winding, which is made of finer wire than the other coil of the cut-out. The heavier coil is connected in series with the cut-out contact points. When these points are closed, this heavier coil carries the current to the battery.

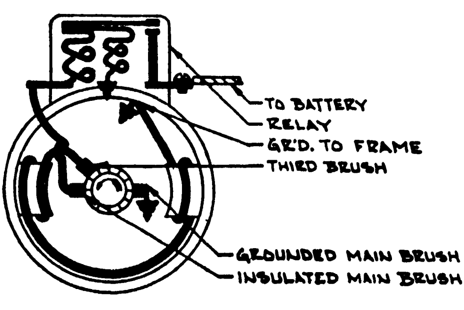


Fig. 110 — Cut-out diagram

As the generator speed increases, the output becomes greater and, when the generator is delivering between 6.3 and 7.5 volts (4 to 12 mph of the car), the magnetic pull of the core of the cut-out coils is great enough to close the contact points by pulling down the armature against the pull of the spring. This allows practically all of the current output of the generator to flow through the heavy cut-out series winding and on to the battery, to keep the battery in a charged condition, and to supplement the battery in supplying current for electrical needs of the system. The slight amount of current that now passes to ground in the cut-out shunt coil winding is sufficient to hold the contact points closed as long as the generator voltage is above a predetermined value.

When the engine speed falls below this set value, the battery voltage is higher than the voltage output of the generator, and the reverse current in the series winding of the cut-out from the battery, aided by the reduction in current from the generator, collapses the magnetic pull of the cut-out core. Under these conditions, the armature spring separates the contact points, thereby opening the circuit from the battery, so that the battery will not discharge through the generator.

The cut-out is either in its own apparatus box or in the same apparatus box with the vibrating regulator of output of the generator. As will be noted, knowledge of the cut-out is needed for an understanding of each of the four commonly used methods of regulation of generator output which follow.

1. Third-Brush Regulation of Current Output.—The third-brush system of control, while extremely simple in mechanical construction, is somewhat obscure in its electrical operation. This is due to the complex internal characteristic of the generator known as "armature reaction" which is fundamentally involved in the performance of the system.

To render the following description of the third-brush system as clear as possible, the elementary theory of the electrical generator, and especially the subject of armature reaction, will be reviewed briefly before explanation of the third-brush system proper is taken up in detail.

Generation of electricity depends primarily upon three factors: the strength of the magnetic field, the amount of ampere turns of wire on the armature, and the speed of the mechanical force turning the armature. The voltage of electricity generated is always proportional to the product of these three factors.

Obviously, then, if any one of these factors is increased or de-

creased, a corresponding increase or decrease will be produced in the generated voltage. On the other hand, if one of these factors is increased by any given amount, the voltage can still be kept at a constant value by decreasing one of the remaining factors by a proportional amount. This principle is employed in the third-brush control generator, the function of which, as previously explained, is to prevent battery overcharging and overloading of the electrical system.

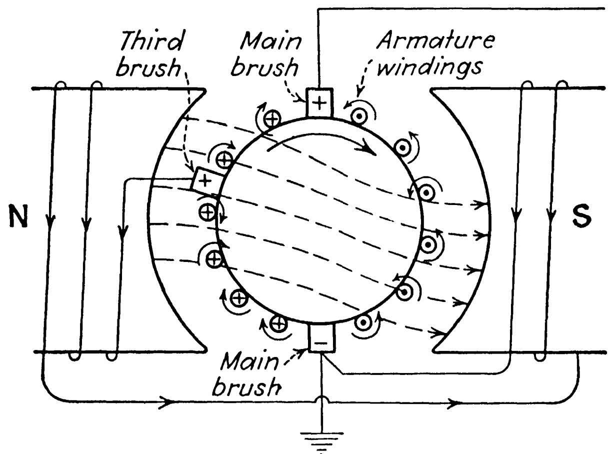


Fig. 111 — Magnetic whirls

Since the number of conductors on the armature cannot be changed while the machine is in operation, the strength of the field must be changed to compensate for increases in speed.

The governing feature of the third-brush control is armature reaction, which is the name given to the effect produced upon the lines of magnetic force in the main generator field by the cross magnetizing force set up by the magnetic whirls which form around the wires of the armature coils when current is flowing through them.

With the main magnetic field established at full strength by the proper exciting current flowing through the field coils, the lines of magnetic force produced will leave the north pole-piece, cross the first air gap, go on through the armature, cross the second air gap, enter the south pole-piece, and return to the starting point in the north pole-piece through the frame of the generator. If no current is flowing through the armature, the residual lines of force will pass in a straight line from the north pole-piece directly to the south pole-piece. The moment that the current begins to flow through the armature coils, as the armature starts to rotate, a secondary magnetic

flux is set up in the armature core in the form of magnetic whirls around each wire in the coils, and this " armature flux " will have a marked effect upon the main magnetic field according to the relative strength of the two component fields (Fig. 111).

The armature flux is made up of two components, one acting in direct opposition to the main field flux and tending to neutralize it.

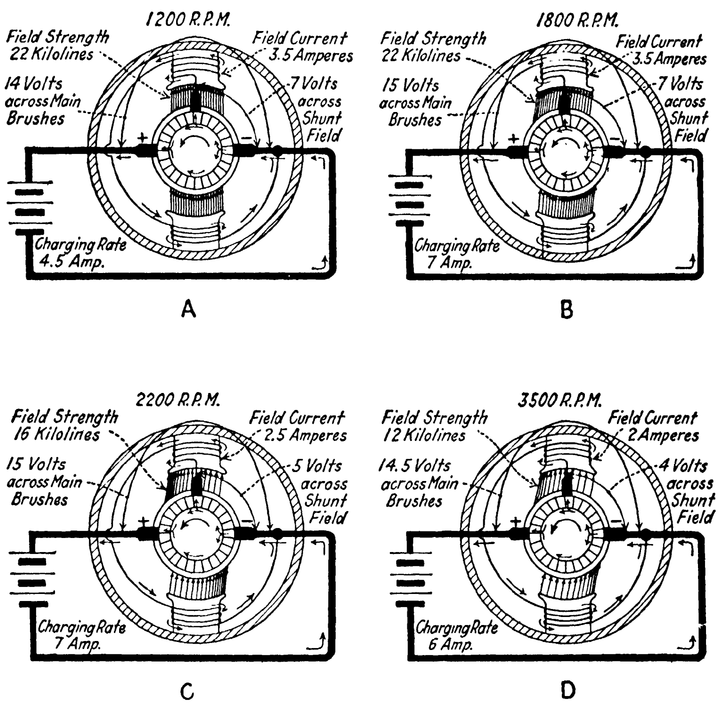


Fig. 112 — Third-brush control

The other component is at right angles to the main field flux and is of the utmost importance in bringing about the desired control of the generator output. It combines with the main field flux to produce a resulting field in which the actual direction of the lines of force is proportional to the two forces.

By referring to Fig. 112*A* it will be seen that, while the speed of the generator is slow, the main magnetic field lines of force travel straight from the lower north pole-piece to the south pole-piece. As the speed is increased as shown in Fig. 112*B*, the armature flux, consisting of all the magnetic whirls around the wires of the coils, begins to distort the main magnetic field. Referring back to Fig. 111,

the main flux is indicated by dotted lines and the armature flux, by circular arrows. In Fig. 112*C*, the armature is turning at a still faster rate. The main field strength has been weakened in the following manner: the armature reaction has increased somewhat because of the increased armature current. The armature flux — being, therefore, stronger — is distorting the main field more toward the right part of the north pole-piece and toward the left part of the south pole-piece. This is because the direction of the individual and accumulated whirls of lines of force around the armature windings tends to push over and distort the flow of the main field lines of force leaving the right part of the north pole-piece. In the same manner, the lines of force which leave the right part of the north pole are made to enter the left part of the south pole.

It will be seen, then, that the armature coils will cut less lines of force between the main negative brush and the third brush at the top than are shown in *A* or *B*. This results in a lower field current and voltage, and also in a weaker main magnetic field. This is offset, however, by the increased speed. Therefore the voltage between the main brushes is of the same value at *C* as in *B*.

At *D* of the figure are shown the generator conditions when operating at 3500 rpm. At this speed, the voltage across the shunt field winding has dropped to 4 volts, because of the very decided distortion of the lines of force of the magnetic field. This materially reduces the field strength which, in turn, reduces the number of lines of force flowing between the poles. This reduction in the field strength has been proportionately greater than the increase in the armature speed. Therefore, the voltage across the main brushes has been decreased and, consequently, the charging rate has been reduced.

As the speed increases above this point, the armature reaction will cause a greater distortion of the lines of force in the magnetic field and the voltage between the negative brush and the third brush will materially decrease, thereby reducing the field strength, which will diminish the voltage between the main brushes, which in turn will diminish the generator output.

From the foregoing explanation it will be seen that the output of a generator equipped with a third-brush control will increase from zero to the maximum, then taper off as the speed increases. As the machine operates practically as a straight shunt-wound generator until it reaches its peak of output, the rise in output will be very rapid. The amount that the output drops off after it reaches its peak will depend upon the construction of the generator, each individual ma-

chine having a different armature reaction. Another virtue of this type of generator is that changing the location of the third brush will change its output characteristics. Moving the third brush in either direction will cause it to bear a different relationship to the armature reaction and therefore the voltage between the third brush and the negative brush will be changed, thus changing the field strength and consequently the output. These characteristics are attained, however, only when the battery is in the circuit. Any break in the circuit is liable to allow the voltage to rise, resulting in damage to the electrical system.

The purpose of the diagrams in Fig. 112 is not to show the exact numerical values of the voltage, the current, and the magnetic flux that would exist in any particular generator under practical operating conditions, but to point out the general interrelationship among several factors which affect the control of the generator output when third-brush control is used.

2. Third Brush in Combination with Vibrating Voltage Regulator. — The vibrating voltage regulator is used in conjunction with the third-brush system. With the third-brush system alone, the voltage and current output of the generator will increase as the battery becomes fully charged. Of course, the current output will not exceed the limit set by the third brush, but the voltage may rise as high as 8 or more volts. By addition of a voltage regulator, the charging rate can be varied according to the amount of charge in the battery, and held to a top voltage of about 7.2 to 8 volts. When the battery is low, the current output is high, not exceeding the limit set by the third brush and, when the battery approaches full charge, the current passing into the battery is of low amount. This affords better protection to the battery. The third brush is not adjustable when used in conjunction with a vibrating voltage regulator, thus the current output is limited by the position of the third brush.

Following is a description of the passage of current from a third-brush generator with cut-out relay and vibrating voltage regulator. Note Fig. 113. The current passes from the positive main brush through the cut-out relay as already explained, to the ammeter. From the ammeter the current divides and goes into three branches: one branch leads to the lights and other electric appliances (not shown); a second branch runs to the battery, thereby keeping the battery in a charged condition and is grounded through the frame of the car back to the negative main brush of the generator; the third branch runs to one side of the ignition switch. When the ignition switch is turned on, the current passes from the battery and the

generator through the ignition system and also passes through a coil of many turns of fine wire around an iron core in the voltage regulator where the circuit is grounded.

A spring holds the contact points of the voltage regulator closed until the battery is charged to a predetermined voltage. As the battery approaches this voltage, the current acts through the fine voltage winding of the regulator to magnetize the core sufficiently to draw down the armature against the tension of the spring, thus opening the contact points.

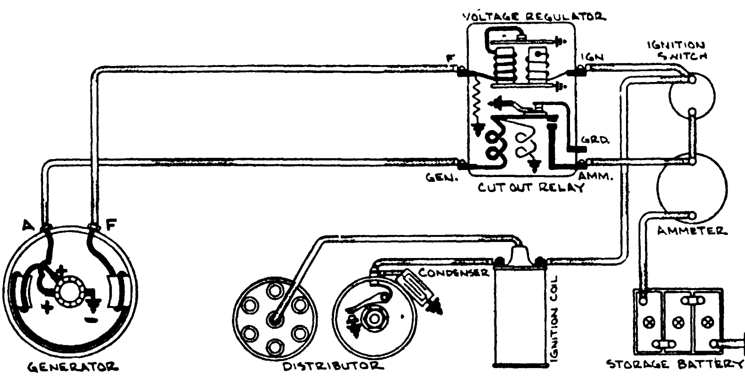


Fig. 113 — Third brush in combination with vibrating voltage regulator

The other winding in the regulator is of a few turns of heavy wire. When the contact points are closed, the entire current from the third brush passes through the field windings of the generator and is grounded after passing through the regulator points and the armature. This current assists the other regulator winding in opening the contact points.

When the contact points are opened, the current from the generator field circuit then passes through the resistance shown in Fig. 113 to ground. This resistance in the circuit will naturally weaken the generator main field and therefore the generator output to the battery. This lower output will demagnetize the regulator cores so that the spring will close the contact points, and the same operations will repeat as often as the battery reaches the predetermined voltage.

A bimetallic hinge is usually employed on the regulator armature so that more voltage will be required to open the contact points in cold weather than in hot because, in cold weather, higher voltage is necessary to charge the battery than in hot weather.

3. Vibrating Current Regulator. — In recent years, the vibrating

current regulator has come to be used frequently in the place of the third-brush type of regulation. When this is the case, the generator has but two main brushes as shown in Fig. 114.

It will be noted that, although the current through the voltage regulator passes through the coil to ground, the windings of the current regulator are in series with the current passing to the battery at all times. This means that the contact points will vibrate continuously, thus keeping the current flowing at a constant value regardless of engine speed.

After the current leaves the positive main brush and passes through the cut-out, it then passes through the two windings on the current

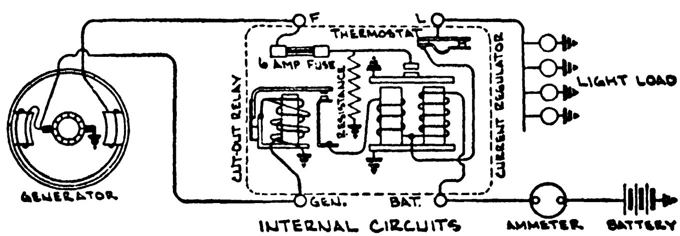


Fig. 114 — Vibrating current regulator

regulator, through the ammeter to the battery. As the current builds up to the maximum output, limited by the setting of the regulator, the cores are magnetized and attract the regulator armature down, separating the contact points. The current passing from the positive main brush through the generator field windings is therefore weakened, because the current through the field windings now passes through the resistance, which reduces the current through the field windings. This in turn weakens the main magnetic field, which decreases the amount of current generated through the current regulator to the battery.

As soon as the current through the windings of the regulator drops in voltage, the regulator cores lose enough magnetism to allow the spring to pull up the armature and close the points, thereby cutting out the resistance which again allows the generator field to build up. Continuous opening and closing of the contact points in this manner keeps a constant value of current passing into the battery. All grounds return through the frame of the car to the negative main brush to complete the circuits.

4. Vibrating Voltage and Current Regulator. — The current and voltage regulators are built in the same apparatus box with the cut-out relay, and this unit is used with a two-brush generator. This

is the method of regulation most commonly used in modern passenger cars.

With this combination, the current regulator keeps the current output from exceeding a predetermined amount and works independently of the voltage regulator, thus preventing the battery from receiving current at a rate exceeding the predetermined value. By comparing Fig. 115 with Figs. 113 and 114, the relationship between the regulators when used separately and together will be seen.

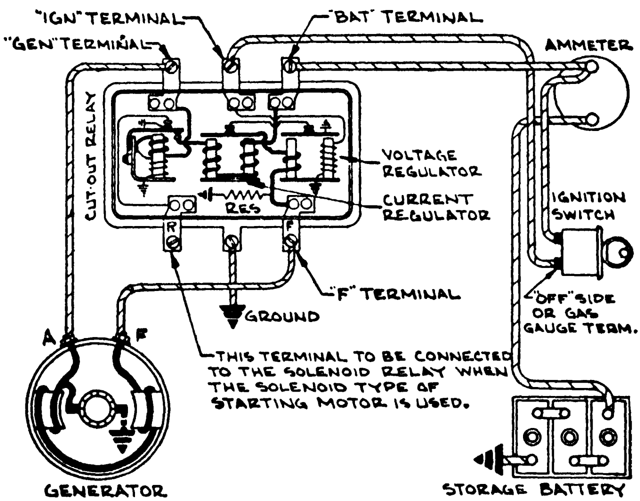


Fig. 115 — Vibrating voltage and current regulator

Not under any condition will the generated voltage exceed about 7.2 to 8 volts. Not under any condition will the amperage output exceed 20 to 36 amp, the number depending on the generator used. Most modern passenger-car systems are set for 27 to 36 amp. The only condition which would be an exception to the above for a regulator in good condition would be when the armature spring tension became too strong and thereby kept the contact points closed until a higher current or voltage value was built up to overcome the higher spring tension and open the points. This spring tension is adjustable to manufacturer's specifications.

If the battery voltage is low, the voltage regulator points remain closed, and the current from the generator will be sufficient to charge the battery and supply current for the ignition, radio, lights, or other connected load, but will not exceed the amount set by the current regulator. As the battery becomes charged, the current regulator will allow less current to pass into the battery, but enough for the

connected load. The voltage regulator will begin to operate at the predetermined voltage of about 7.2 to 8 volts. In this way the battery will be properly charged — high amperage to low battery, low amperage to high battery — and the lights will be protected so they will not burn out.

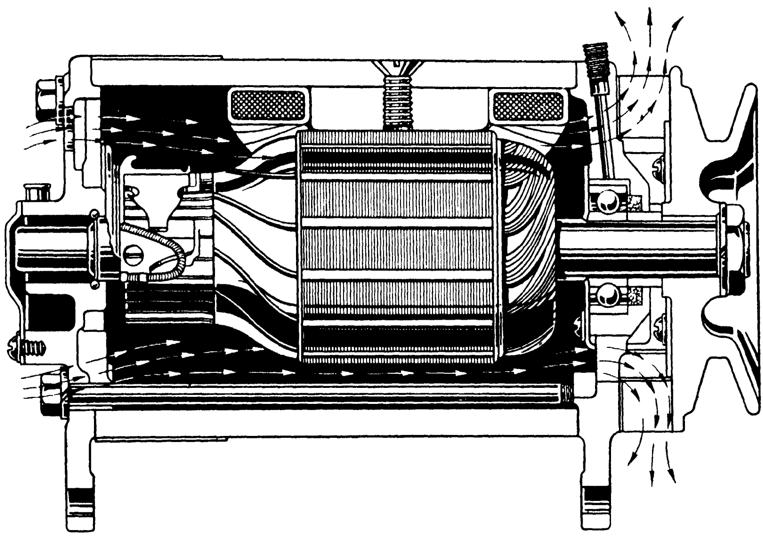


Fig. 116 — Typical shunt-wound generator, showing fan and air flow

Passenger-car generators are usually mounted at the front of the engine so that they can be driven by the engine from the same belt that drives the fan. Gears or chains are also used. To provide increased cooling, modern motor-vehicle generators are provided with a fan to draw air through the generator. See Fig. 116.

CHAPTER XVIII

THE AUTOMOBILE ELECTRICAL SYSTEM

Should the electric system of a modern automobile be viewed first as a road map, it would be found to contain four main circuits or trunk roads and a great number of branch circuits, corresponding to secondary roads serving a particular community.

A bird's-eye view will reveal these four main highways (Fig. 117) as being the generating circuit, the starting circuit, the ignition circuit, and the lighting circuit. Branches (not shown in Fig. 117) serve special-purpose lights, radio, gasoline gage, cigar lighter, heater, windshield wiper, defroster, or any one of several other accessory units.

The main highways will be examined first.

The generator circuit (part of which — the generator and its controls — was described in Chapter XVII) starts in the generator and runs through its controls to the battery.

The starting circuit begins at the battery positive terminal and is completed after passing through the starter cable, solenoid switch, through the starting motor and back to the negative battery terminal through the frame of the car.

Current enters the ignition circuit at the ammeter, either from the battery or from the generator, follows through the circuit's low-tension line to ground, and returns through the frame of the car to the battery or generator grounded brush.

The lighting circuit, too, receives its current at the ammeter, either from the battery or from the generator. The current then passes through the wiring of the lighting switches and lights and thence to ground.

Detailed descriptions of each of these main circuits, except the previously-described generator circuit, follow:

Starting System. — The starting motor is supplied with its current through heavy No. 1 or No. 0 gage cable because it draws a current of between 75 and 350 amp, the higher current being used in colder weather and to turn over the larger engines. As explained previously, starting motors are series wound to produce maximum torque, and have four poles. It is important to have starting cables of ample size because, at the same time this heavy current is being

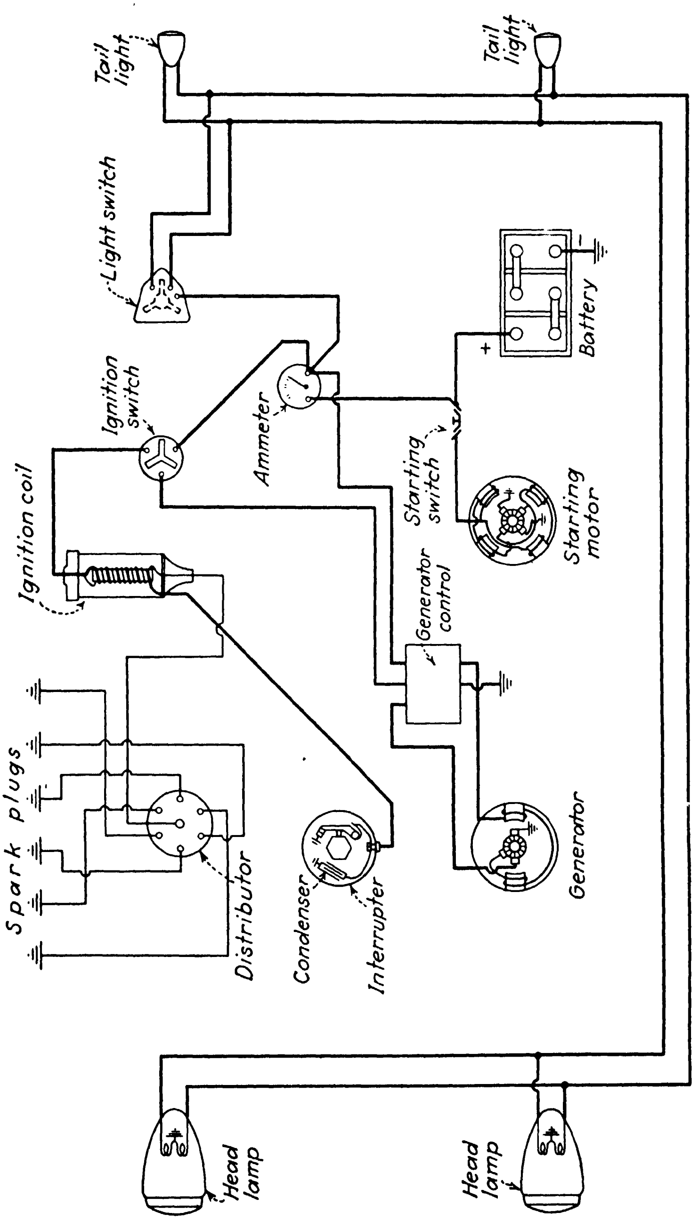


Fig. 117 -- Four main circuits of automobile electrical system

supplied to the starting motor, it also is being supplied through the same cable to the ignition system to produce the spark at the spark plugs to get the engine running. If the starter cable were too small, it would not carry enough current to do both jobs. The longer the cable, the larger must be its diameter — to cut down excessive voltage drop. When the starting motor is turning the engine over, about 5 volts are available at the battery — and 4 of these are needed for the starter.

As can be seen from the wiring diagram, the current used in the starting motor is not shown on the ammeter. This is because the starter is used so little that indications of the current that it uses would have little practical value. For this reason, ammeters with which passenger cars are equipped record only up to 30 or 35 amp — far less than the amperage used by the starting motor.

Two types of starting-motor drives are in common use: (1) the Bendix drive and (2) the overrunning clutch.

The Bendix Drive. — The collar next to the armature winding (Fig. 118) is fixed rigidly to the shaft with a bolt. The other parts of the Bendix drive are free from the shaft and collar excepting for

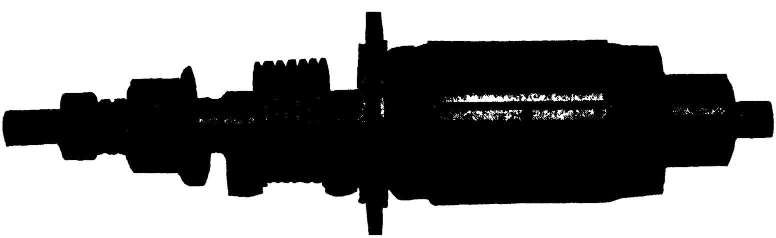


Fig. 118 — Bendix drive

their connection through the spring. The spring is attached to this collar and also to the spiral-threaded sleeve carrying the pinion. This sleeve is not connected directly to the shaft of the starting motor but only uses it as a bearing. The pinion has a female thread inside, which fits on the spiral thread of the sleeve.

When current is first passed into the starting motor, the armature immediately starts to revolve at full speed. This turning effect is transmitted through the collar and spring to the threaded sleeve. The pinion, because of its inertia of rest and its unbalanced weight (lower right on pinion in Fig. 118), turns very little but is moved outward by the spiral thread until it engages with the teeth of the flywheel. A slight turning effect is given to the pinion as it moves out, so that its teeth do not travel in a straight line. This slight

turning reduces the possibility of the teeth not meshing properly with those on the flywheel. When the pinion has traveled to the end of the thread it strikes the collar at the left and is forced to turn with the threaded sleeve, thus causing the flywheel and crankshaft to turn and crank the engine. The shock of the start is relieved by the spring connection between the armature shaft and the threaded sleeve.

After the engine starts, it turns the pinion much faster than does the starting motor, and would ruin the latter if the starter pinion

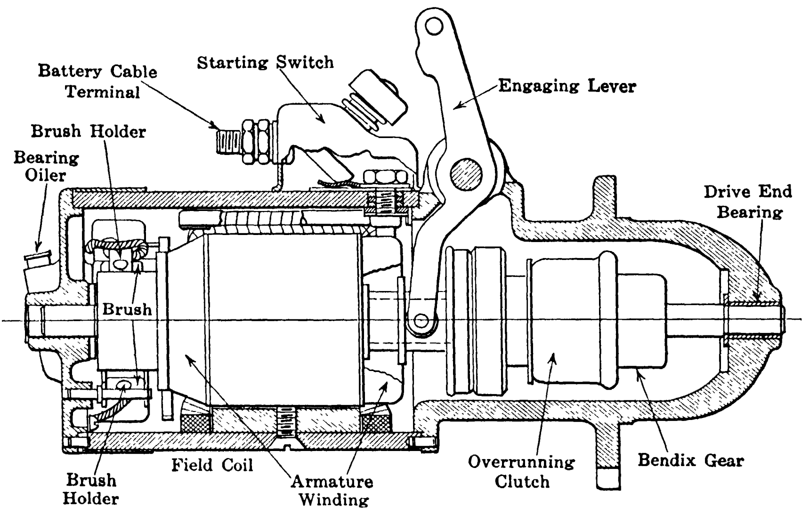


Fig. 119 — Overrunning clutch drive

and flywheel gear remained in mesh. These gears are automatically disengaged, however.

Disengagement takes place because, at the time the engine actually starts, the pinion is being turned by the engine much faster than when rotated by the starting motor. As a result, when the starter button is released by the car-operator, the pinion screws back on the spiral-threaded sleeve, out of mesh with the flywheel gear — thus protecting the starting motor.

The Overrunning Clutch Drive. — Fig. 119 shows a starting motor with mechanical gear shift and overrunning clutch drive to the flywheel of the engine.

As the starting pedal is pushed down, the drive is pushed forward in a spline fit on the armature shaft and, if the pinion teeth on the drive align with the gear spaces on the flywheel, the pinion will mesh fully with the flywheel before the starting switch is closed. If the pinion does not mesh, it will be pressed back into the cup housing

as the drive is pushed forward; and, as soon as the starting switch is closed, the pinion will turn and the pressure of the spring in the housing against the pinion will force the pinion in mesh when the teeth do align.

As soon as the engine starts, the overrunning clutch comes into action. This unit is so constructed that, as the starting motor turns, the pinion is driven positively through the overrunning clutch. But, as soon as the engine starts, the pinion turns so much faster than the starting motor that it would ruin the starting motor were it not for the action of the overrunning clutch, which allows the pinion with its increased speed to slip backward into the overrunning clutch unit. As soon as the starting switch is opened, the engaging lever releases the pinion from the flywheel gear.

Starting-Motor Controls. — Four types of starting-motor control are used on modern passenger cars:

1. Solenoid magnetic switch
2. Solenoid switch with relay
3. Vacuum switch with solenoid relay control
4. Coincidental starter switch

Solenoid Magnetic Switch. — After the ignition switch is turned on and the circuit closed through the starter pushbutton switch, current passes from the battery (Fig. 120) through the heavy battery

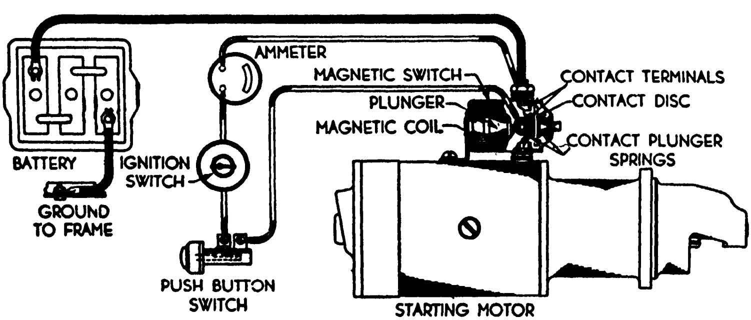


Fig. 120 — Solenoid magnetic switch

cable to the terminal on the magnetic switch. At this point the current divides, some going through the wiring through the ammeter, the ignition switch, and the starter pushbutton switch to a terminal on the magnetic switch — and thence through a coil winding in the switch to ground. The remainder of the current passes through the other coil in the solenoid to ground. This latter cur-

rent energizes the contact plunger, enabling it to complete the circuit across the starting motor terminals and allows the current to pass from the battery cable to the starting-motor field coils and brushes. This passage of current turns the starting motor and causes the starter pinion to engage with the flywheel gear. When the plunger contacts the two terminals, the current passing through the wire of the larger coil is reduced to almost nothing, but the current through the other coil is sufficient to hold the starter gears in mesh, giving all the current to the starting motor necessary to perform its function. In this type of starter control, the starter pushbutton should be released as soon as the engine starts, since the starter will continue to turn as long as the button is held in.

Solenoid Switch with Relay. — The difference between this type and the switch just described is that a relay is installed in conjunction with the solenoid. Referring to Fig. 121, it is seen that, after the

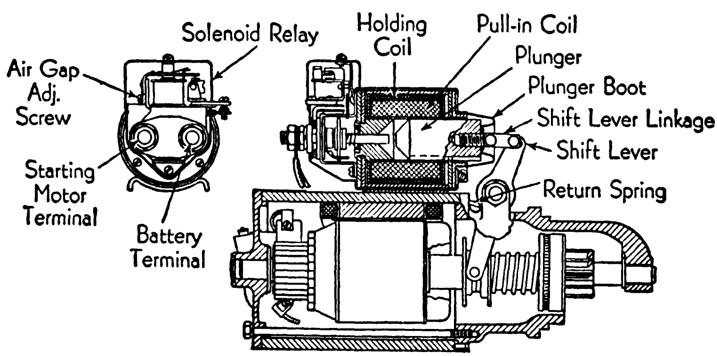


Fig. 121 — Solenoid switch with relay

ignition switch is turned on and the starter pushed in to close the starter circuit, the current passes from the battery to the upper contact points in the relay and through its coil. After it has passed through the coil, the current is grounded at one of two places: either direct to the starter frame or to the upper contact point of the generator cut-out.

As the current passes through the solenoid relay coil, the energized core pulls down the armature and the points make contact, thus allowing the current to pass through the coils of the solenoid as described previously, closing the starting-motor circuit and engaging the starter gears.

As stated above, the current passing through the relay is grounded in one of two places. If it is grounded directly to the starter frame, the starter pushbutton should be immediately released when the

engine starts, as the starting motor will continue to turn as long as the starter pushbutton is in. When the current is grounded through the upper generator cut-out points, this circuit is opened when the generator speed is supplying enough current to close the cut-out points, thereby rendering the starter solenoid inoperative as long as the engine is running, and the generator is charging enough to keep the cut-out points closed.

Vacuum Switch with Relay and Solenoid Control. — This combination operates in similar manner to the solenoid with relay. It

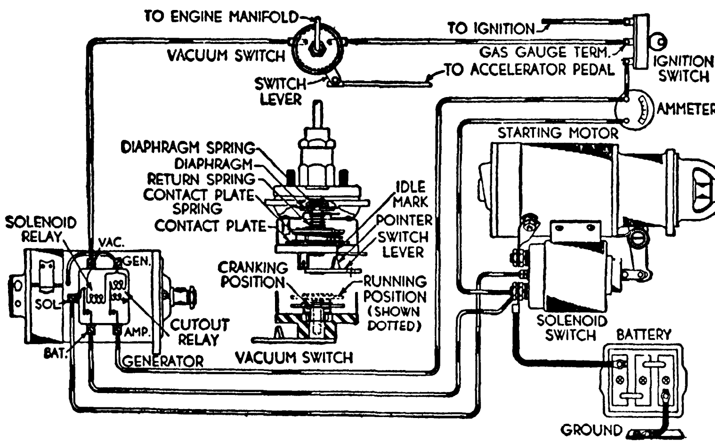


Fig. 122 — Vacuum switch with relay and solenoid control

provides, however, an automatic opening of the solenoid circuit to stop the starting motor as soon as the engine begins to run. This is in addition to the automatic release provided with the relay by opening its circuit through the operation of the generator cut-out points (Fig. 122).

The vacuum switch operating lever is attached to the accelerator pedal, and when the pedal is depressed the rotary vacuum switch contacts are closed. This closing allows current to pass through the solenoid relay, thereby completing the circuit which engages the starter gears. As soon as the engine starts, the intake vacuum acts on the vacuum switch diaphragm, drawing the rotary switch away from the contact plate which opens the solenoid switch circuit. Opening this circuit allows the starting motor to stop and the starter pinion to be released from the flywheel gear. This action allows the accelerator to be used then only as such so long as the engine is running. When the engine is stalled or stopped, the vacuum is no longer present in the vacuum switch, and depression of the acceler-

ator pedal again will allow the rotary arm in the vacuum switch to complete the circuit through the starter solenoid.

Coincidental Starter Switch. — (Fig. 123.) As the clutch pedal is depressed, the operating lever, attached to the clutch, turns counter clockwise and pulls the switch lever roller arm, which is pivoted near its center. The roller pushes the switch blade so that the blade makes contact at the starting-motor terminal, completing the circuit from the battery to the starter, and the starter gears are engaged. As soon as the engine starts, the vacuum from the intake

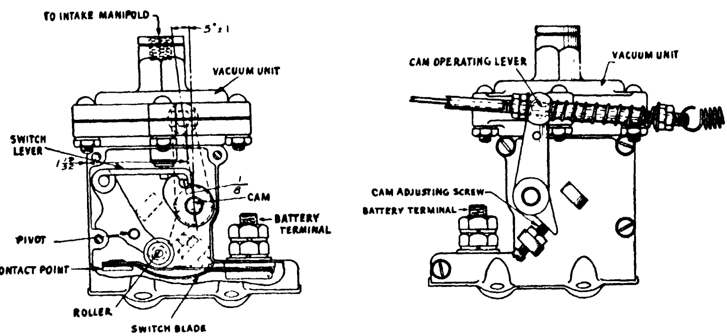


Fig. 123 — Coincidental starter switch

manifold pulls up the diaphragm in the vacuum unit which raises the switch lever so that further contact with the operating cam is impossible as long as vacuum is provided by the running engine of the motor vehicle.

Ignition System. — The ignition system is that part of the electrical system which carries the electrical current to the spark plug which produces the spark necessary to ignite the fuel as it enters the combustion chamber.

Many means are employed to produce the necessarily high voltage required to jump a set gap, all of which are based on the principle of mutual electro-magnetic induction. Ignition systems are classified under two general headings: (1) battery ignition systems and (2) magneto ignition systems. Battery ignition systems, universally used on passenger cars and light trucks, employ a coil to obtain the necessary voltage, receiving the current for the primary circuit from the storage battery.

In Fig. 117 is shown a typical battery ignition system for a six-cylinder engine. As explained in Chapter IV each of the four strokes of the piston performs a particular function. The power stroke is the one that keeps the engine running, because during that stroke

the pressure caused by expansion of the burning gases drives the piston downward and causes the crankshaft to turn. It is a spark that jumps across the spark-plug gap which ignites the compressed mixture that causes the power stroke.

The primary ignition circuit starts at the battery and passes through the ammeter, the ignition switch, the heavy or " primary " winding about the soft-iron laminated core of the coil, through the ignition points to ground. One end of the condenser is attached to the primary circuit and the other end is grounded. Inside the condenser are many sheets of tin foil connected to each terminal, and each sheet is insulated from the next by waxed paper.

The secondary coil winding is not connected electrically to the primary. It starts from ground in the coil, runs through about 18,000 turns of fine wire, and then passes through a heavily insulated wire into the center of the distributor cap. A carbon contact carries the current to the rotor, which, as it revolves, distributes the current to the six segments which, in turn, send it to the spark plugs through the spark-plug wires. After the current jumps the plug gap, igniting the gasoline mixture, it is grounded.

When the ignition switch is turned on, the current is allowed to pass through the primary coil winding and thence through the ignition points to ground.

The distributor shaft on which the rotor is placed is turned by the camshaft. At the top of this shaft, just under the rotor, there are six lobes or cams, one for each of the six cylinders in the engine shown in Fig. 117. Each time a cam passes by the rubbing block of the insulated ignition point, it separates the points, thus breaking the primary circuit. The distributor shaft is so meshed with the camshaft that, near the upper end of each compression stroke of the pistons, the lobes of the distributor shaft will open the points. As explained in Chapter VII, it is necessary that a particular cam open the points for the power stroke of a particular piston every two revolutions of the crankshaft.

Each instant that the points are opened the spark occurs at the spark plug of a particular cylinder and the piston is pushed down on its power stroke. About 10,000 volts are necessary to make the spark jump a gap of between 0.025 in. and 0.040 in., as it does in the spark plug when the gasoline and air mixture in the cylinder is under compression. The voltage induced in the secondary winding of the coil depends upon the ratio of the number of turns in the two windings, upon the sizes of the wires, and also upon the variation of the current strength in the primary circuit.

This high voltage is produced by mutual induction as explained in Chapter XVI. As long as the ignition points are closed and current is passing through the primary circuit, magnetic lines of force are building up inside the coil. As soon as the points are opened, these lines of force collapse and are attracted to the iron core of the coil. In passing the secondary winding of the coil, these magnetic lines of force set up a current with the very high voltage necessary to jump the spark-plug gap.

Of course, as the lines of force are being built up, there is a voltage induced in the secondary winding, but the voltage reaches the nec-

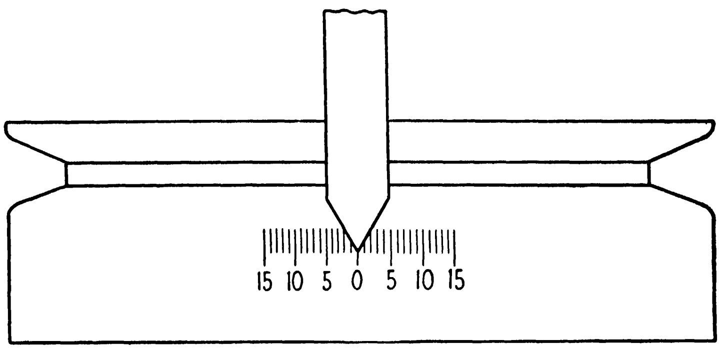


Fig. 124 — Timing marks and pointer

essary magnitude only when a complete and sudden collapse of the lines of force occurs by the opening of the points. This collapse is further aided and quickened by the condenser. The condenser absorbs the electricity in the primary circuit which was on its way to pass through the ignition points, but which was suddenly stopped by their separation. This absorbed current surges back out of the condenser and toward the coil, thus helping to complete collapse of the lines of force in the coil. By its absorbing qualities, the condenser also minimizes the arcing and pitting of the points.

The spark in each cylinder must occur at a definite time. This is accomplished by timing the ignition. The rotor can only be put on the distributor in one way. As the rotor turns, it passes by the segments in the distributor cap. Each segment is connected electrically to a spark plug by a spark-plug wire. As has been mentioned, the high-tension or secondary current passes from the coil into the center of the distributor cap where it is transmitted by a carbon brush to the center of the rotor. The current then passes along a conductor within the rotor and, each time the end of the rotor passes a brass segment in the distributor cap, current jumps

the short gap and passes from the segment to the spark plug by way of the spark-plug wire.

To be sure that the spark plug fires in a cylinder when its piston is near the top of the compression stroke, the distributor shaft is meshed with the camshaft so that the rotor is directly opposite the segment in the cap that will carry the secondary current to the particular cylinder at the same instant. At this time current jumps from the rotor to the segment from whence it flows to the spark plug.

The cams on the distributor shaft are so placed that, when the rotor is properly timed to No. 1 cylinder, for example, the points in the primary circuit will just start to separate as a pointer on the front end of the engine points to a mark on the flywheel or vibration damper (Fig. 124), indicating that No. 1 piston is near the top of the compression stroke, and that the spark should next occur in that cylinder. On some cars, the timing marks are on the flywheel and a pointer is on the flywheel housing.

When the ignition points are open, they should have a clearance of between 0.015 in. and 0.025 in. depending on the manufacturer's specifications.

The following instructions should help in the understanding of the foregoing:

To time the ignition of a particular engine, first look up the manufacturer's specifications for ignition-point clearance, and the number of degrees before top dead-center of piston travel when the spark should occur. Turn the engine by hand until No. 1 piston is coming up on the compression stroke and stop when the pointer at the front of the engine points to the correct mark on the vibration damper or flywheel, indicating when the spark should occur. Install the distributor, meshing its drive end with the camshaft so that a cam on the distributor shaft is just about to open the points. The rotor will point to a segment in the distributor cap. Install a spark-plug wire connecting No. 1 spark plug with the segment in the cap to which the rotor is pointing. This will insure a spark at No. 1 plug when No. 1 piston is ready for the power stroke. Then place in proper firing order the remainder of the spark-plug wires in the distributor cap.

The cam angle is the number of degrees travel of the distributor shaft that the ignition points are closed (Fig. 125). Special equipment is available to adjust the point clearance to the specified cam angle. Otherwise, a feeler gage is used. The importance of the correct cam angle lies in the fact that it is during the time the points are closed that the coil is " building up " so that, when they are

opened, the proper amount of high-tension current will be available at the spark plugs. If the points are adjusted too closely, the engine will not run evenly if at all, as the points will not open long enough to give the coil a chance to do its work. If the points are adjusted with too much clearance, the engine will miss at high speeds, because the points will not be closed long enough to allow the coil to build up properly. The result will be a weak spark at the plugs.

The spring tension of the insulated ignition point must be within specifications, usually around a 20-oz pull when tested with a pull scale, made for the purpose. If spring tension is weak, the ignition

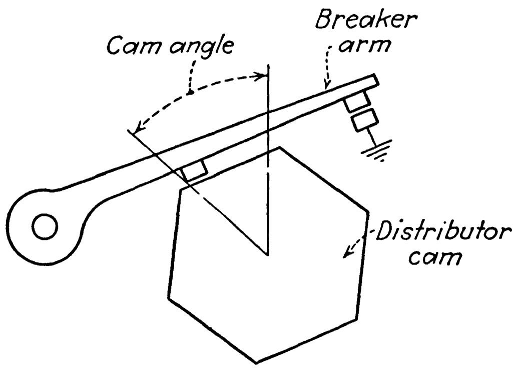


Fig. 125 — Cam angle

point will " flutter " and cause missing, particularly at high speeds. If the spring is too strong, it will wear away the rubbing block and points at an excessive rate.

The purpose of the centrifugal governor shown in Fig. 126 is to advance the spark automatically as the engine increases its speed. Ignition timing, as just explained, is done while the engine is not running. Usually, manufacturers specify that the spark should occur a few degrees before top dead-center for starting the engine, or when it is idling as explained in Chapter VII. When the engine is speeded up, the governor weights swing out, pivoted on their pins and against the tension of their springs. As they swing out they " advance " the spark by turning slightly in a direction opposite to the rotation of the distributor shaft the plate on which the ignition points are fastened. As can be seen this will cause the cams to separate the points sooner. Thus, the spark will occur in the cylinder a little in advance in the piston travel as the piston approaches top dead-center. As the engine is slowed down again, the springs attached to the governor weights overcome the centrifugal force tending to keep the weights in the outer position, and thus retard

the spark. Spark advance is necessary at high speeds to get the full benefit of the power stroke. On account of the greater piston speed, and the time required to get the full benefit out of the burning mixture in the cylinder, it is desirable to start the mixture burning a little earlier in the compression stroke so that, by the time the piston is starting down on its power stroke, the burning mixture is ready

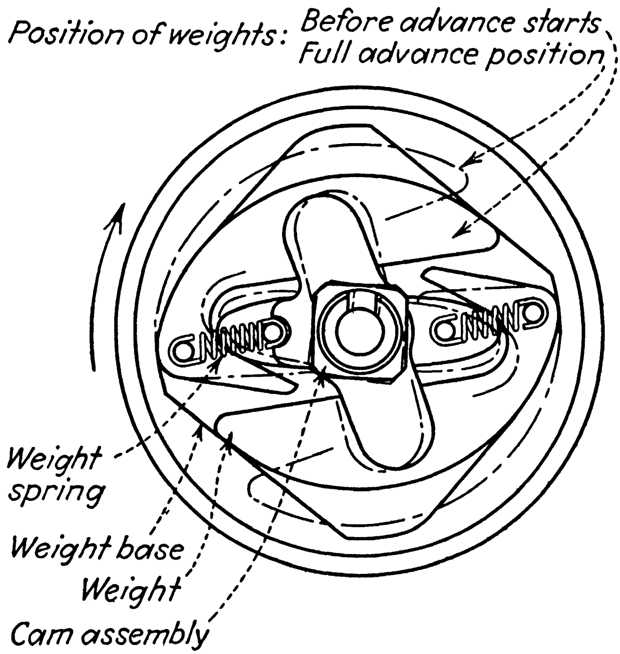


Fig. 126 — Centrifugal governor weights

to give all its expanding power to useful work. On the other hand, if the spark were left in the fully advanced position necessary at high speeds, the engine would not start, since the spark would occur when the piston had progressed so little on its compression stroke that the burning mixture would stop the piston in its tracks, trying to send it back down again; the piston does not have the inertia that the high speed gives it, and cranking speed is too slow to overcome the expansion of the burning mixture.

There are certain running conditions such as pulling up a hill at an average speed, or quickly accelerating the car, which tend to give a full-open throttle with full car load. For best engine performance under these conditions it is best to have a somewhat retarded spark, so the engine will not " ping " or " knock." The compression is higher when the throttle is opened suddenly as for ac-

celeration and full-load work, and this higher compression causes the mixture to burn faster. So, with a normally advanced spark, the greatest efficiency will not be received from the burning mixture.

To retard the spark while the engine is under heavy load and not accelerating, or to check the automatic spark advance if the engine

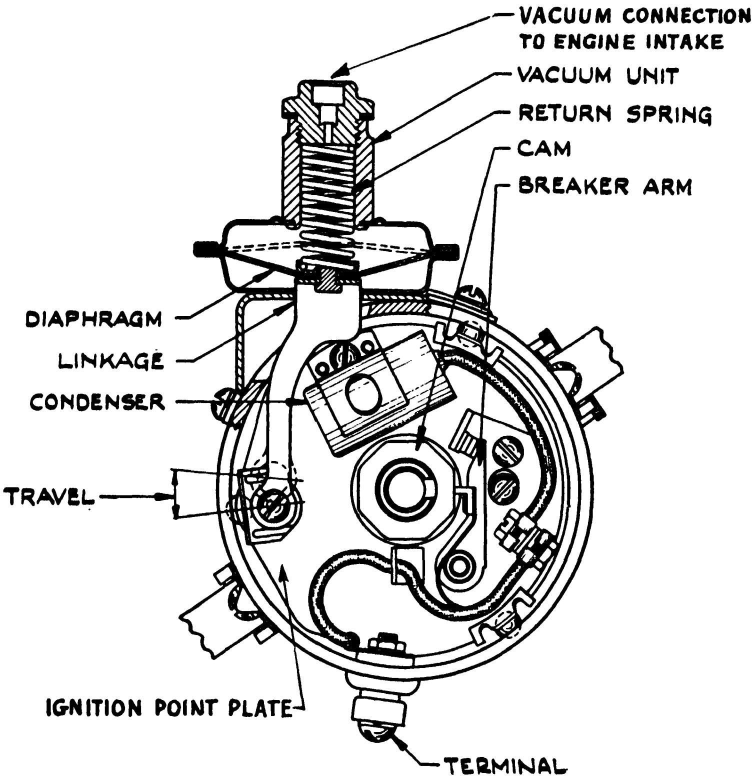


Fig. 127 — Vacuum spark control

is accelerating, a vacuum control is used (Fig. 127). A copper tubing connects the control unit with either the intake manifold or a point just above the throttle butterfly valve in the carburetor. The spring in the control unit moves the diaphragm (which, in turn, is linked to the ignition-point plate in the distributor) toward the distributor when the vacuum is low and the engine is under heavy load or rapid acceleration, thus moving the plate in a direction tending to retard the spark. This spring will exert its full pressure only when the vacuum in the copper tubing is not great enough to pull back on the control unit diaphragm. When the vacuum increases (as when

the car is " cruising ") it will overcome the pressure of the spring acting against the ignition-point mounting plate and allow the governor weights to advance the spark. The vacuum in the line is high when the engine throttle is held for an even, light-load speed. The vacuum is low when the throttle is opened allowing in more air and gasoline, such as for heavy engine load, or quick acceleration.

The combination of the centrifugal weight and vacuum spark control gives the engine practically perfect spark timing for all driving conditions.

Lighting System. — Lights are used in modern motor vehicles for a wide variety of purposes. Headlights are necessary to illuminate the highway sufficiently to permit safe night driving. These are usually provided with two or more beams, one of which provides maximum illumination for night driving, and another of which is so designed as to permit deflection to the ground and to the side of the road to minimize glare when passing other cars on the road. When a third beam is used, it is usually of low intensity for city driving. Tail lights are used to illuminate the rear of the car, including the license plate, so that both car and license plate can be seen by drivers of other vehicles. Tail lights usually incorporate stop lights which flash red whenever the brakes are applied. In addition to the headlights, low-intensity parking lights usually are provided in the front of the car, either as separate units or as part of the headlamps.

The lighting system also includes lights inside the body to illuminate the compartments in which the passengers ride, special lamps to light the instrument panel, and sometimes special lights to illuminate the keyhole for the ignition key or the inside of the glove compartment. Map lights, trunk compartment lights, radio dial lights, and clock lights are also provided on some cars. Flashing signals on the front and rear to indicate to other drivers the direction in which the car is about to be turned have been finding wider application in recent years.

In addition, one or more special lights, designed as signals to the driver, may be incorporated. Such special lights may include a red signal light to indicate when the " country " beams of the headlights are burning; when it is possible to go into overdrive (on cars where such a unit is used) ; to indicate when the gasoline supply is low; to indicate that the oil pressure is low; that the cooling-water temperature is too high; or that the battery is discharging at too rapid a rate.

Fig. 117 shows the wiring for the headlamps and tail lights of a typical passenger-car lighting system. The circuit is a single cir-

cuit, employing one wire and ground. Current is supplied to the system from the battery and/or generator at 6 to 8 volts. Suitable switches and fuses or circuit breakers to protect the system from overload also are included in the system.

Automotive lamps are of the incandescent gas-filled type. To give a definite idea of their size and number, a typical medium-priced car has two 45–35 watt headlights, two 3-cp parking lights, one 3-cp license-plate light, two 21–3 cp stop lights and tail lights, four 1.5-cp instrument lights, one 1.5-cp map light, one 6-cp dome light, one 1-cp beam indicator, one 1.5-cp trunk compartment light, one 1.5-cp radio dial light, one 1.5-cp clock light, and one 1-cp glove compartment light.

Of these, the headlights are the only ones requiring adjustment. For this reason, and also because of their importance to safe driving, the headlights will be taken up in more detail.

"Sealed-Beam" Headlight System. — In the early days of the automobile, car speeds were low and there were relatively few vehicles on the road. For this reason the kerosene or acetylene lamps then in use for headlights provided adequate illumination. As road speeds were stepped up, more powerful headlamps were required and provided. Unfortunately, the number of cars on the road also increased rapidly, and the problem of glare from the more powerful headlamps of passing cars became acute. To solve these problems a two-beam headlamp system, called the "sealed-beam" headlight system, was developed. Both lamps in this system are alike and produce a straight-ahead or "country" driving beam and a deflected or "traffic" beam in which the light from both beams is deflected to the right side of the road and slightly downward to minimize glare. This new system, which appeared first on 1940 models, was the result of three years' cooperative work by car manufacturers, bulb and lamp manufacturers, safety organizations, the Society of Automotive Engineers, and motor-vehicle administrators. It is designed to provide the safest seeing that is technically practical, and has had almost universal adoption on American cars.

The maximum intensity of the country beam, which is for use only when there is no approaching traffic, is specified at 75,000 cp, as compared with the previous maximum of 50,000 cp. Actually the maximum intensity of the country beam is about 60,000 cp. The traffic or passing beam is directed low enough to avoid glare and directs sharp, clear illumination to the side of the road, especially to the right shoulder as shown by the light pattern at the top of Fig. 128. The traffic beam is directed downward and to the right by locating

the traffic filament in a position slightly eccentric with the center of focus of the parabolic reflector. Lenses are designed especially to direct and distribute the light rays as desired.

In construction of the sealed-beam headlamp, the lens, reflector, and light source are all assembled permanently in a sealed unit. When the filament burns out, the unit is replaced with a new one. An important advantage is that their sealed construction permits these lights to maintain at least 90% of their original efficiency until

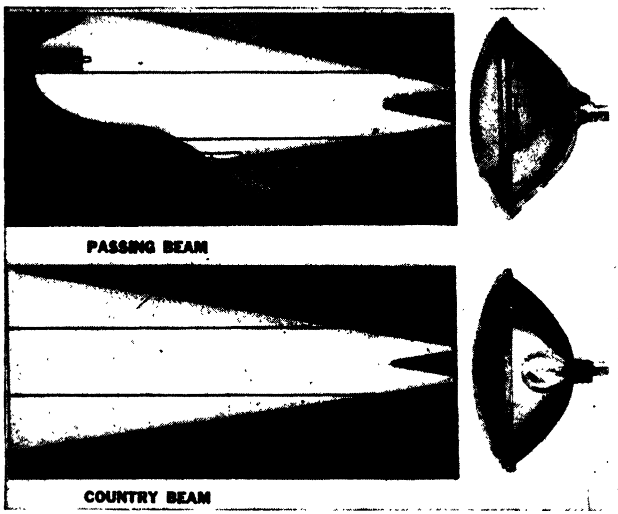


Fig. 128 — Sealed-beam headlight system — Beam patterns (left) and basic types of headlamp unit

they burn out, where other types may lose from 33% to 66% of their efficiency during their life, depending upon how well they are cleaned and maintained. The reflector unit in the new headlamp is held to a sub-body by a retainer ring and three screws which may be loosened for removal of the unit. The sub-body forms a ball-and-socket joint with the lamp housing and is held to the housing by four coil springs, plus a vertical adjustment screw and a horizontal adjustment screw. With this type of mounting, the horizontal light-beam adjustment can be made without disturbing the vertical light-beam setting and vice-versa, as shown in Fig. 129. The reflector unit is provided with three locating lugs which fit into corresponding slots in the sub-body. These lugs are so located that the reflector unit can be mounted only in one position, as shown in Fig. 130.

The headlamp unit is made in two basic types — one with a glass reflector and the other with a metal reflector. The glass-reflector

type shown at the upper right in Fig. 128 is its own bulb and employs a 40-watt filament for the country beam and a 30-watt filament for the traffic beam, whereas the metal-reflector type shown at the lower

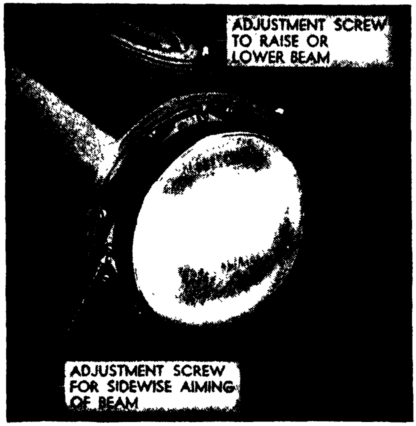


Fig. 129 — Aiming adjustment of sealed-beam headlights

right contains a conventional bulb with 45- and 35-watt filaments respectively. These values compare with the 27- and 20-watt filaments used for 32-cp bulbs in other lighting systems. The two types

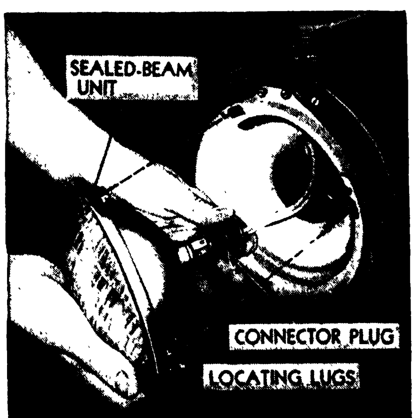


Fig. 130 — Removing a sealed-beam unit

give the same light distribution on the road and are interchangeable so that a metal unit may be used to replace a glass unit or vice-versa. Glass reflectors are aluminum-plated, whereas metal reflectors are silver-plated.

Control of the new lighting system has been standardized on all cars in which it is used so that either country or traffic beams can be obtained alternately by operation of a left-foot pushbutton switch, and so that a red pilot light on the instrument board is illuminated whenever the country beam is in use.

A control switch on the instrument board also is used for operating the sealed-beam system. This switch usually has three positions: " off," " parking," and " driving."

Aiming Adjustment of Sealed-Beam Headlights. — Adoption of the sealed-beam system has simplified the aiming of headlamp beams greatly because the instructions for aiming the headlamps of all cars with sealed-beam lighting are the same. Typical instructions for aiming follow:

" To obtain the maximum results in road illumination and the safety that has been built into the headlighting equipment, *the headlamps must be properly aimed.*

" Place the car on a level stretch with a light-colored vertical screen 25 ft ahead. For best road lighting results, draw a horizontal line on the surface at the level of a point 3 in. below the headlamp center. If, however, your state requires a loading allowance, draw this horizontal line below above-mentioned line, by the amount required by your particular state. Sight through the center of the rear window over the center of the radiator ornament and so determine a point on the horizontal line midway between the headlamps. Draw vertical lines through points at the right and left of this center point directly ahead of the center of each headlamp. On cars equipped with a divided windshield, it is necessary to locate a point on the horizontal line by sighting past the left edge of the center divider and then past the right edge. A point midway between these two points represents the centerline of the car on the screen from which lines directly ahead of the headlamp centers can be located.

" Place lighting switch in the position which produces the country (upper) beam (bright lights). When the country (upper) beam is lighted the lower filaments on both lamps are illuminated.

" Independent adjustment of both horizontal and vertical aim is provided in ' Sealed-Beam ' headlamps with adjustment screws accessible from the front of the lamp after first removing door rim. The light beam is moved to the right or left by tightening or loosening this horizontal adjusting screw. The beam may be raised or lowered by turning the vertical adjusting screw (Fig. 129).

" Cover one lamp to obscure the beam of light and then adjust the beam from the other lamp so that the center of the zone of highest

intensity falls on the intersection of the horizontal line 3 in. below the headlamp center and the vertical line directly ahead of the lamp. Repeat the operation for the other lamp. No further adjustment is needed for the traffic (lower) beam."

Other Systems. — Before the introduction of the sealed-beam system, headlamps with three as well as two beams were in wide use. A low-intensity beam for city driving, a high-intensity "upper" beam, and a passing beam usually comprise the three beams. The passing beam often is depressed on the left side to remove the glare from the approaching driver's eyes, with a high beam on the right side. As a result, right and left headlamps of such systems are not interchangeable. Because of the wide variation in construction and aiming instructions of such systems, the manufacturer's service instructions should be referred to for any such information.

Direction Signals. — These devices are incorporated into the lighting systems of many cars to indicate to other drivers which way the driver intends to turn his car. In operation, lights are caused to flash about 80 times per minute on the side of the car toward the direction in which the car driver intends, or has started, to turn. Since the flashing lights usually are combined with the parking lights in front and the tail lights in the rear, they attract the attention of drivers in front or back of the car.

Fig. 131 shows one design of direction-signal system. In this arrangement the direction-signal lights are turned off automatically at the completion of a turn, but they also may be turned off manually. The switch lever for operating this mechanism is located under the steering wheel above the gearshift lever, and is flipped up for left turns and down for right turns. Left or right pilot lights on the instrument board in the form of arrows flash when the direction signals on the corresponding side are in operation. The automatic turn-off is accomplished by a mechanism that breaks the circuit when the wheel returns to straight-ahead position. The front signals flash from the 21-cp filaments of the parking lights located directly on top of the fender above the headlamps. The rear signals have 32-cp flashing lights.

Servicing the Electrical System. — In servicing the electrical system, it is best to have each circuit in the mind's eye as a separate unit. This will eliminate confusion and unnecessary work in tracing down the trouble. (Refer back to Fig. 117.)

Troubles in the generator system can be isolated in the generator itself, or in the regulators, or in the cut-out, or in the wiring between them and through the ammeter to the battery.

If the indicator on the instrument panel shows that current is not passing from the generator to the battery, the voltage and current regulator should be cut out and tested with a voltmeter and ammeter, according to manufacturer's specifications. In this way it can be determined whether the regulators are at fault or whether

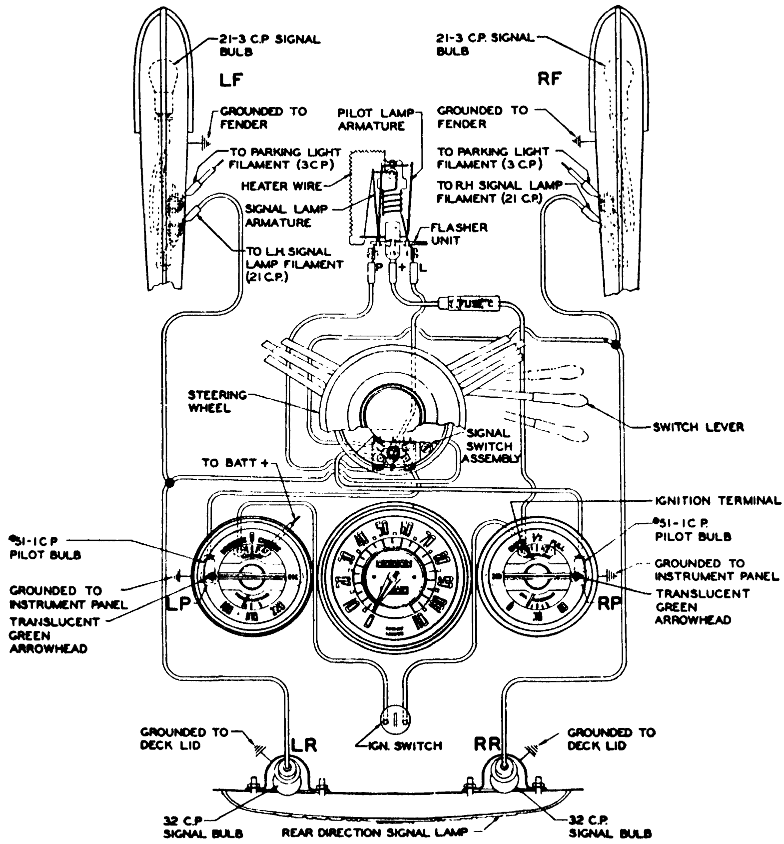


Fig. 131 — One type of direction-signal system

the generator is not charging. If the tests show the trouble to be in the regulators, the contact-point adjustment should be checked and cleaned with a fine-cut file. (Sandpaper should not be used as it may cause a short circuit.) The armature spring tension should be increased or decreased to specifications and the armature air gap set to the proper clearance. If these adjustments do not correct the trouble, it is best to replace the faulty regulator with a new one. These regulators give very little trouble as a rule, and filing the

points for better contact will usually put them in good order, as the points receive the most wear.

If the tests show that the generator is not charging, the commutator bars should be cleaned with sandpaper while the engine is idling.

If the generator does not charge after this, it is necessary to remove the unit and put it through the following tests: (1) Take the generator apart and clean all the parts in gasoline. (2) With a 110-volt lamp and test prods, test for short circuits between the insulated brushes and ground. (3) Test the field windings for continuous circuit and for grounds, and replace if found defective. (4) Test for broken wires. (5) Test the armature and commutator bars for short or open circuits.

In testing for short circuits, the armature should be put in a special tester called a " growler " which is made for the purpose. When making this last test, it is important that the space between the commutator bars be clean; otherwise, a short circuit might be caused. If defective, the armature should be replaced. If the commutator bars are rough and dirty, it is best to turn them down on a small lathe, after which the mica insulation between the bars should be undercut so that the bars will not interfere with the brushes when the generator is running. Dirty and noisy generator brushes, if not worn excessively, may be cleaned and trued with the commutator bars by means of sandpaper. Emery cloth is not suitable for this purpose as it will short-circuit the bars.

Mechanical trouble in the generator frequently turns out to be in the bearings on the armature shaft. These bearings should be oiled with a little light oil every 1000 miles, and replaced if worn out. The pole pieces should be screwed tightly to the housing, and the drive pulley should be tight on the armature shaft.

A generator using only third-brush regulation will charge more than the required amperage if the brush is set too far in the direction of rotation of the armature. If the generator is not charging at all or very little, the brush should be pushed in the direction of armature rotation. If this does not increase the charging rate, the trouble probably is dirty brushes, a dirty or rough commutator, or internal trouble which should be checked as just mentioned, by taking the generator apart.

When voltage and current regulators or only voltage regulators are used, the generator should show a low charging rate when the battery is fully charged. A high charging rate under these conditions indicates trouble somewhere within the regulator or generator field. If the battery is low and the charging rate is low, a loose con-

nection somewhere in the generator wiring system as far as the battery might be indicated. Such a loose connection might also cause burned-out bulbs or flickering lights.

A loose fan belt or weak generator brush springs will decrease the charging rate, since the belt will not turn the generator fast enough and the brush springs will not hold the brushes tight enough against the commutator to conduct the full amount of generated current.

In general, the troubles in the electrical system that are the most likely to happen are the simplest to repair. These common troubles include dirty or rough regulator points, a dirty commutator, and dirty or worn brushes.

Starting Motors and Controls. — The units of the starter system requiring service are the motor, the drive-gear assembly, the starter controls (such as the solenoid and vacuum switches), and the battery cables. (See Fig. 117).

Loss in voltage between the battery and the starting motor should be kept at a minimum. To insure this condition, cable connections should be tested while the starter is turning the engine over. A low-voltage voltmeter should be used. If the voltage drop between terminals is over 0.1 or 0.2 volt, all connections should be cleaned and tightened or cables should be replaced. A little light grease placed on the terminals of the battery will prevent corrosion. Minimum voltage drop is necessary to permit the starter to receive the needed current, since the starter draws more current than any other device on the car.

Troubles likely to occur in the starting motor are similar to those common in the generator. Dirty or worn brushes and commutator bars will tend to slow down the motor and make it spark at the brushes; the action of the motor, under these circumstances, will be almost the same as if the battery were weak. To remedy this condition, the brushes must be sandpapered or renewed and the commutator bars sandpapered. If the commutator bars are rough and burned, they should be turned down and the mica insulation between them undercut, provided this latter action is recommended by the car manufacturer. Tests for short or open circuits in the field coil, armature, and commutator are made as already described in connection with the generator circuit. Insulated brushes must not be grounded and all parts should be cleaned in gasoline and inspected before re-assembling.

If the starting motor turns over, but the starter pinion does not engage with the flywheel gear, the starter should be removed and the starter drive assembly examined to see if either a spring or a

spring's holding screws are broken. The pinion assembly should slide freely on the screw thread and on the armature shaft, and the shaft should be straight. Linkage between the solenoid plunger and the pinion assembly should be set to factory specifications. If the overrunning clutch is slipping, it should be replaced.

If the pinion does not release from the flywheel, battered gears should be suspected. If examination shows the gears to be meshing too deeply, they should be adjusted by moving the starter slightly for proper alignment. It is important that starter shaft bearings and bushing be kept in good condition and that neither too much end play nor too much side play exist.

Constant reference to manufacturer's specifications is desirable when starter control troubles are being remedied. In general, all electric contacts should be tight and points of the solenoid should be kept clean with a fine-cut file. Piston drive linkage should be set to give proper clearance. All other starter linkage should be kept in adjustment to factory specifications. Where vacuum control is used, all tubing connections must be kept tight to prevent loss of vacuum.

Ignition and Ignition Timing. — When seeking the cause of ignition troubles, it is well to check the primary and secondary circuits separately. (See Fig. 117.) If the primary circuit shows current at the ignition points, it is a good indication that the primary circuit is in good condition. It is possible, however, that the condenser may be at fault. To make certain whether or not this is the case, the condenser should be tested on a condenser tester. If defective, the condenser should be replaced. If, on the other hand, there is no current at the points, the wiring and all connections in the primary circuit must be traced back to the battery. During this test, the ignition switch must be turned on. If current is not found at one connection, but is found at the next toward the battery, the trouble is between these two points. If the test shows that current is not going through the coil, the coil must be tested on a coil tester. If the coil does not test up to factory specifications, it should be replaced. Often an engine will not start if the points are badly pitted or burned. When such is the case, they should be replaced and adjusted.

If tests show the primary circuit to be in good condition, the next step is to ascertain that there is current at the spark plugs. Should there be current at some plugs and not at others, all the spark plugs should be tested on a plug tester. If no current appears at any plug, the coil should be tested as advised previously — and replaced if

necessary. A coil or condenser designed for the particular engine on which it is to be installed should always be used. In the secondary circuit, the rotor and the distributor cap should be examined for cracks or defects through which the high-tension current might leak to another terminal or ground itself. Clean terminal connections in the distributor cap will give good contact. If any high-tension wires have cracked or broken insulation, they should be replaced because the high voltage will jump to ground through poor insulation.

The distributor should be taken out of the engine for checking and should be disassembled on a bench. It is important that there be not too much play between the shaft and the bushing in the distributor housing. When there is too much play, both shaft and bushing should be replaced. If the ignition points are not too badly pitted or burned, they may be dressed on an oil stone for good electrical contact. Centrifugal governor weights and springs must be kept in good condition and working freely; the vacuum-advance control linkage and unit should work freely. In re-assembling the parts of the distributor, the points must be aligned properly for full contact; a little light grease should be placed on the distributor shaft where the rubbing block of the ignition point makes contact. It is important that the insulated point be properly insulated. The spring tension of the insulated point should be adjusted if necessary.

After the distributor has been put in good condition, the ignition points should be set at the proper cam angle, using an instrument made for the purpose. Care must be taken when making these settings, because top engine performance depends as much on the amount of dwell or contact of the points as on when they open. Setting the points at the correct cam angle eliminates the use of a feeler gage. If, however, such an instrument is not available, the points may be set to the specified clearance with a feeler gage.

The ignition points in distributors with two sets of points must be synchronized. This can be done accurately by use of a synchrograph or other instrument which will show how many degrees the movable set of points opens after the stationary set, and how many degrees the stationary set opens after the movable set. Cam angle may also be set at this time. If one of these instruments is not available, the distributor should be replaced — in correct time.

To achieve this correct timing, a neon timing light is used. With the engine idling, the stationary distributor points are first set to open at the correct time. Then, with the distributor clamped, fol-

lows setting of the movable points so that they break at the right time.

This same neon timing light may be used also to make certain that the governor weights and vacuum control are working properly. For this purpose, the engine is speeded up and the timing light used to check, according to specifications, the advance of the timing mark on the flywheel or vibration damper.

Lighting System Service. — Great variation in headlight intensity through different driving speeds is usually indicative of a battery not fully charged. Both very bright lights and unsteady lights indicate a loose connection which may bring about the burning out of a lamp. Such loose connections often are caused by a poor ground between the lamp body and the frame of the car or fender.

Fuses, when a part of a lighting system, protect the bulb and the battery. The burning out of a fuse, however, is an indication of trouble which should be found. Otherwise, the same thing will probably happen again.

Each time a headlight bulb is replaced, the headlamps should be focused, as explained earlier in this chapter if of the "sealed-beam" type.

A check on the grounding of the lamp should be made as part of the process of trying to trace an open or a short circuit in the wiring of the lighting system.

Special equipment is available for checking headlight efficiency and focus. The headlamps have two setscrews as a rule, one for setting the beam horizontally, and the other for setting it vertically. (See instructions given earlier in this chapter and Fig. 129.) Exact specifications can be obtained from the car manufacturer's manual.

It is essential to safe driving that headlamps always be properly focused.

CHAPTER XIX

POWER TRANSMISSION

The power developed by the engine requires certain parts to transmit this power to the wheels of a motor vehicle. The application of the engine power to the driving wheels through these parts is called "power transmission." The units comprising the power transmission system are much the same on all modern passenger cars and trucks, but their arrangement may vary according to the method of drive and the type of units used. In the power transmission systems of modern automobiles will be found: (1) a clutch; (2) a transmission or gear set; (3) driveshaft or propeller shaft; (4) universal joints; (5) rear-axle gears or final drive; and (6) axles extending to the wheels (or chain sprockets on some trucks). The rear-axle gears are made up of the bevel gears and the differential.

When the power is transmitted to the rear wheels only, as is the case with all American passenger cars, the arrangement of the parts is as shown in Fig. 132. The power is transmitted from the engine through the clutch to the transmission, through the universal joint, then through the propeller shaft to the rear-axle gears. The rear-axle gears transmit the power to the rear wheels through the axles. Sometimes a second universal joint is used between the propeller shaft and the rear-axle gears. When an overdrive is used, it is interposed between the transmission and propeller shaft; its housing is usually bolted to the transmission housing.

In front-wheel drives the powerplant is turned end for end and the differential is built into the transmission and universal joints are required in the driveshafts on the front axle.

The following chapters discuss the different units making up the power-transmission system in the order in which the power is transmitted from the engine to the rear wheels in American passenger cars. The functions and operation of representative types are treated fully.

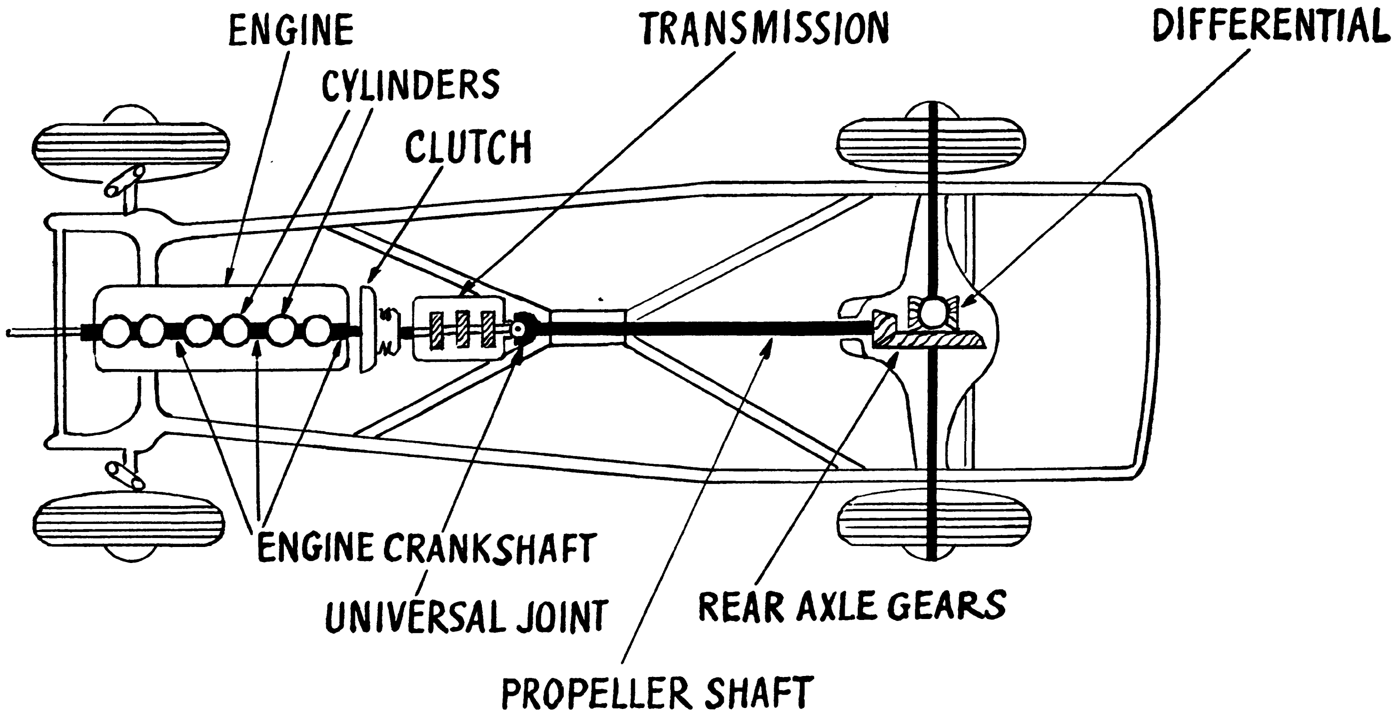


Fig. 132 — Automobile power-transmission system

CHAPTER XX

POWER TRANSMISSION — THE CLUTCH

The function of the clutch is to disconnect the engine from the remaining parts of the power-transmission system at the will of the driver by operation of a foot pedal, thus permitting the engine to run without driving the car. The requirements of efficient motor-vehicle operation dictate that the clutch be " thrown out," thus disconnecting the engine, when starting, when shifting gears, when stopping, and when idling, although the engine usually is idled by shifting the transmission or gear set to the " neutral " position.

A clutch has one member positively driven by the engine and the other attached to the transmission shaft. When these members are separated, by pushing down the clutch pedal, the engine will run without turning the transmission shaft, thus permitting the gears to be shifted easily, the engine to idle, or the car to be stopped without stalling the engine. The friction surfaces of the clutch are designed so that the driven member slips on the other when the pressure is first applied. As the pressure is increased, the driven member is brought gradually to the speed of the driving member. When the speeds of the two members become equal, slippage ceases entirely, the two making firm contact. The drive is accomplished by the friction between the two members, which depends upon the materials in contact and the pressure forcing them together. This force is maintained by spring pressure and must be sufficient to prevent slipping when the clutch is engaged fully, and the surfaces must be of such material as to provide sufficient friction to carry the load. When the clutch pedal is pushed down, the spring or springs are compressed, thus freeing the engine from the transmission line. The clutch must be easy to operate, requiring as little exertion as possible on the part of the driver. It must not take hold too suddenly or it will cause jerky operation of the car and put a tremendous strain on the rest of the power-transmission system. In modern passenger cars the driven member is made as light as possible so that it will not continue to rotate for any length of time after the clutch has been thrown out.

Although there are many types of clutches, the dry single-plate type of friction clutch is used exclusively in American passenger cars.

The word " dry-plate " type is used to distinguish these clutches from those that operate in a bath of oil, known as the " wet-plate " type. Although of the same general single-plate dry type, passenger-car clutches differ in the type of springs used to press the driving and driven members together when the clutch is engaged, most designs using a number of coil springs but some employing a diaphragm or conical-type spring. The type of friction material also varies in different passenger-car clutches. Details of these differences follow.

Fig. 133 shows a typical clutch that has been taken apart. The

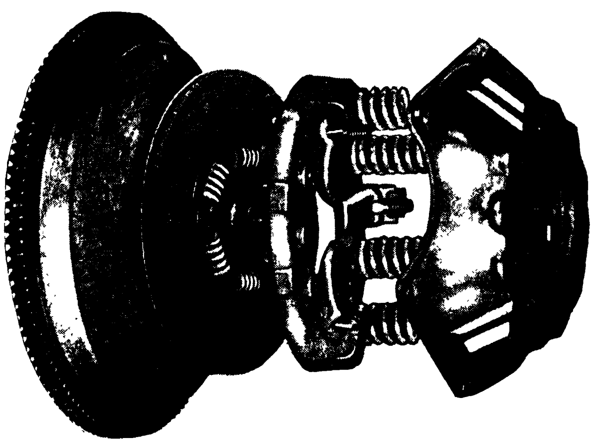


Fig. 133 — Parts of a single-plate clutch

principal parts are the **driving member,** the **driven member,** and the **operating members.**

The **driving member** consists of a cover which carries a cast-iron pressure plate or driving disc, the pressure springs, and the releasing levers. The cover is bolted to the flywheel and rotates with it at all times. The flywheel acts as a clutch part, the flywheel and pressure plates gripping the driven member between them under the action of the pressure springs. To dissipate properly the heat generated by friction in operation of the clutch, the clutch housing and cover are provided with openings for ventilation.

The **driven member** consists of a disc or plate which is free to slide lengthwise on the splines of the clutch shaft but which drives the shaft through those same splines. The clutch disc carries friction material on both bearing surfaces.

The **operating mechanism** consists of the foot pedal, the linkage, the release or throw-out bearing, the release levers, and the springs necessary to insure the proper operation of the clutch.

When the driver presses down on the foot pedal to release the clutch, the motion is transferred, through suitable linkage (Fig. 134 left pedal) to the clutch release fork or lever which moves the release bearing (Fig. 135) forward toward the flywheel. This motion

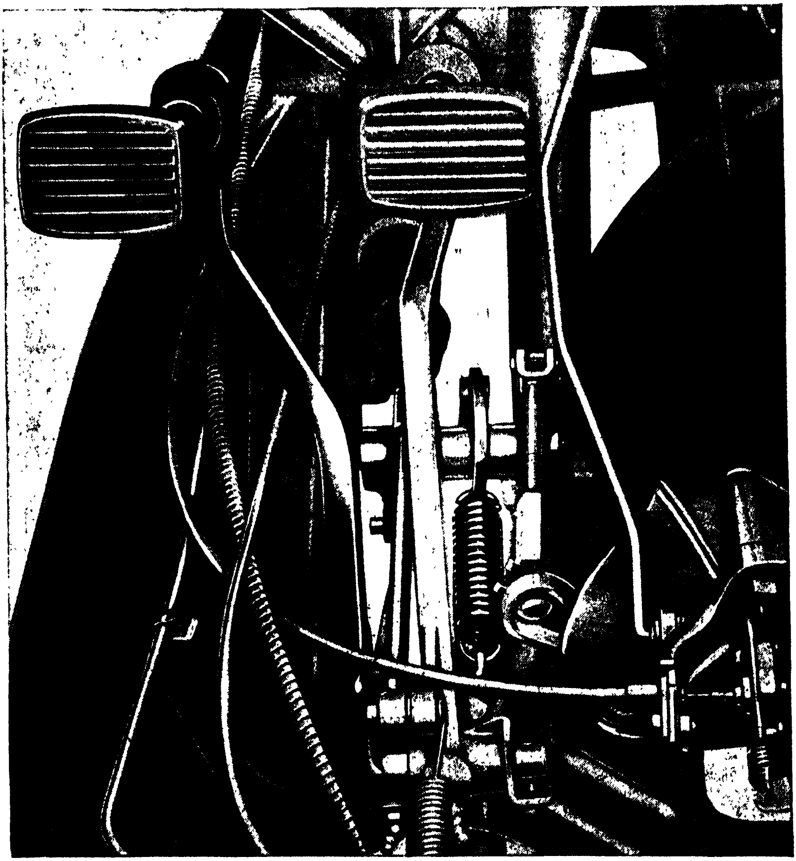


Fig. 134 — Clutch pedal and operating linkage (left)

is transmitted to the ends of three radial release levers which bear on the end of the release bearing. The release levers are pivoted to the clutch cover as shown in Fig. 135 with their outer ends connected to the clutch pressure plate. It is now evident that a relatively light pedal pressure and a relatively large release-bearing displacement toward the flywheel is translated by the pressure-lever linkage to a high pressure and small displacement pulling the pressure plate away from the driven plate and flywheel, opposing the action of the pressure springs, and throwing out the clutch.

The typical clutch plate, shown in Fig. 136, consists of a splined hub to which is riveted a central disc or plate. The central plate is slotted for the insertion of the driving or torsional coil springs. On one side of the central plate is a wavy clutch plate and, on the other side, is a spring-retaining plate. These two plates are riveted together and can rotate with respect to the hub to the limit of the

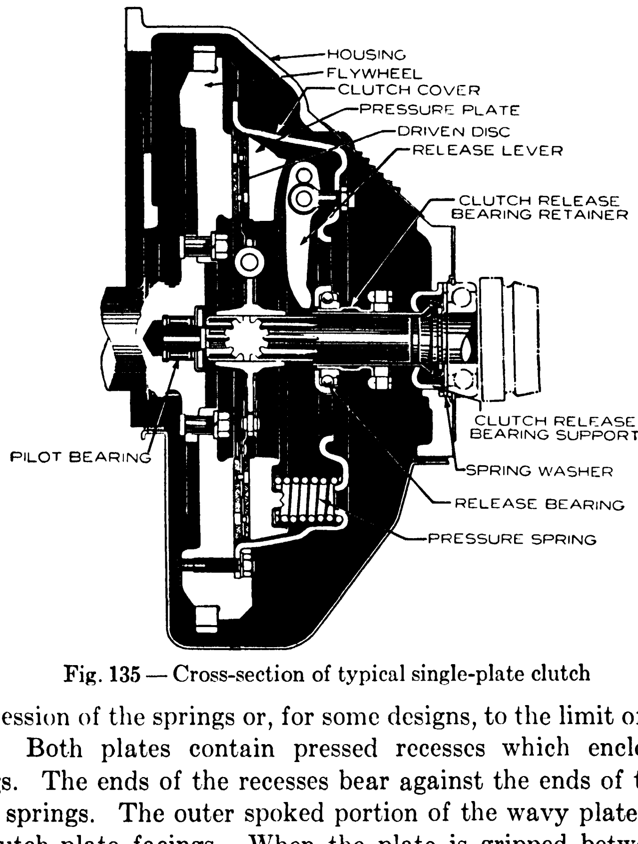


Fig. 135 — Cross-section of typical single-plate clutch

compression of the springs or, for some designs, to the limit of spring stops. Both plates contain pressed recesses which enclose the springs. The ends of the recesses bear against the ends of the torsional springs. The outer spoked portion of the wavy plate carries the clutch-plate facings. When the plate is gripped between the flywheel and the clutch pressure plate, the wavy lining and clutch plate flatten while the clutch plate, together with the retainer plate, transmits the rotating force to the central plate through the springs. These torsional springs act to damp out torsional vibrations and shocks between the engine and the remainder of the power-transmission system.

Friction material usually is made of asbestos fiber, in either woven or molded form, although cork — in the form of circular buttons — is used on some models. Woven or molded facing is riveted to the

clutch plate by one or two rows of rivets and is grooved, as shown in Fig. 136. The grooves offset the tendency of the facing to adhere to the flywheel and pressure plate surfaces after full lining contact, thus permitting easier and quicker release of the clutch.

Woven clutch facing is made by weaving threads of brass or copper wire covered with long-fiber asbestos and cotton. The woven bands or sheets are treated with a bonding solution and are then baked and rolled. Molded facings are made from a matrix of asbestos fiber and starch. The sheets are rolled, pressed, and baked

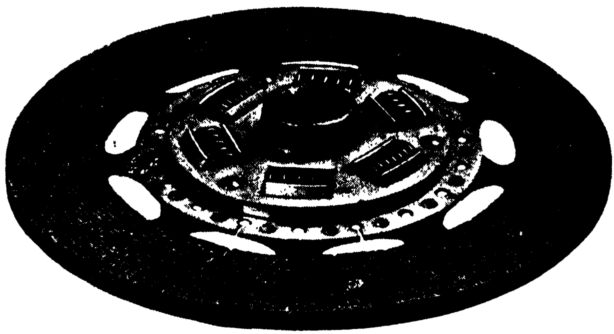


Fig. 136 — Typical clutch plate or driven disc

until they are extremely dense and hard, after which they are straightened and ground to proper dimensions.

Many passenger-car clutches are of the " semi-centrifugal " type shown in Fig. 137 in which the pressure between the plates is increased as the speed of rotation of the clutch increases, in proportion to the pressure requirements. This is accomplished by means of centrifugal weights linked to the pressure plate so that the outward radial pull of centrifugal force is translated into pressure on the plate, this pressure increasing as the speed increases. This construction permits the use of relatively light clutch pressure springs which exert low pressure at idling speeds and thus facilitate depressing the clutch pedal for gear shifting.

Although most clutch pressure springs are of the coil type just described, in some models a one-piece conical spring is used as shown in Fig. 138. This diaphragm or conical spring may have a corrugated or straight surface. The clutch cover acts as a fulcrum for the conical pressure spring. The pressure plate cover, pressure plate, and conical spring are held in position as an assembly by six clutch spring retainers located in driving lugs of the pressure plate and hooked over ears located on the steel cover on one design. The

drive is from the flywheel through the cover, the conical spring, and to the pressure plate to the driven plate. Conical-spring pressure plates need no release levers.

Some conical clutch springs do not have the " constant-rate characteristics " common to most coil springs. Instead, the pressure of the spring increases until it reaches the flat position and decreases as this position is passed. The advantage claimed for this type of spring is that the driver does not have to exert such heavy pedal pressure to hold the clutch out of engagement as with the coil-spring type clutch in which the spring pressure increases further when the pedal is depressed to disengage the clutch.

Another frequently employed method of reducing pedal pressure, especially during the latter part of pedal travel, is to use an " assister spring " in the pedal linkage (Fig. 139).

Other types of clutch, none of which is used on modern American passenger cars, are cone, multiple-disc and double-plate clutches. The double-plate and multiple-disc types, employed frequently in American trucks and buses, operate on the same general principles as those set forth for the single-plate type.

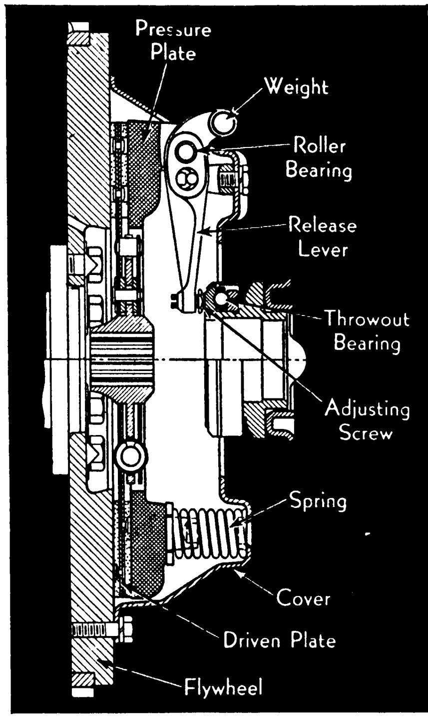


Fig. 137 — Semi-centrifugal type of clutch

Automatic Clutches. — Various types of clutches designed to engage and disengage automatically, thus relieving the driver of the necessity for operating the clutch pedal during normal driving operations, have appeared on passenger cars from time to time. These clutches are usually operated by centrifugal weights, vacuum, or by electro-magnetic means.

After disappearing from American passenger cars for a number of years, a new design of automatic clutch was introduced in 1941.

This clutch is engaged or disengaged in accordance with driving requirements by a vacuum cylinder attached to the intake manifold. The operation of the clutch is controlled by the accelerator pedal; the clutch disengages when the accelerator pedal is released and engages when the accelerator pedal is depressed. A solenoid-operated control valve located in the vacuum line makes the automatic feature of the clutch operative or inoperative as desired. A clutch

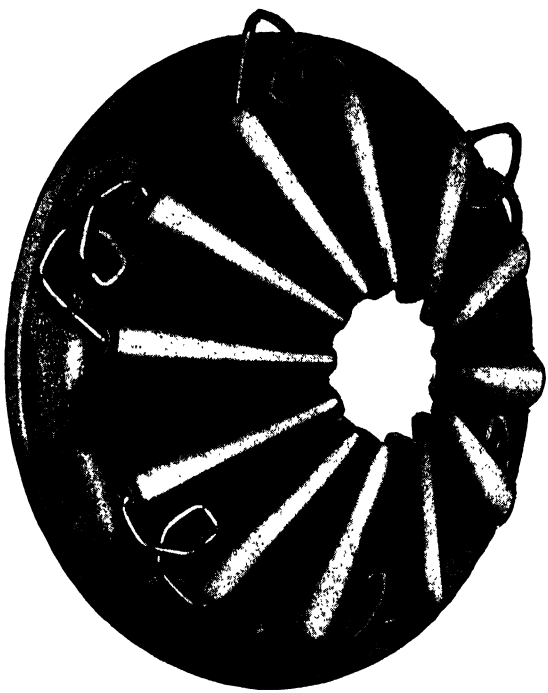


Fig. 138 — Method of assembling conical corrugated clutch spring on pressure plate

pedal is provided which can be used to " override " the automatic operation when desired.

To eliminate free-wheeling in high gear, the automatic clutch does not disengage until the speed of the car has dropped to 10 or 12 mph. An electric centrifugal governor switch is employed to accomplish this speed control of disengagement.

Clutch Troubles. — The clutch is subject to a variety of maladjustments after having been in service for some time. The remedy for many of these maladjustments is suggested almost automatically in a description of the ailment itself. One of the causes of a " slipping " clutch, for example, may be lack of free play in the clutch

pedal. When this is the case, the remedy, obviously, is to adjust the pedal to permit free play.

Five troubles occurring most commonly in connection with the clutch are described in the following paragraphs:

1. **Slipping Clutch.** — A clutch is said to "slip" when there is lack of a firm contact between the flywheel and the pressure plate

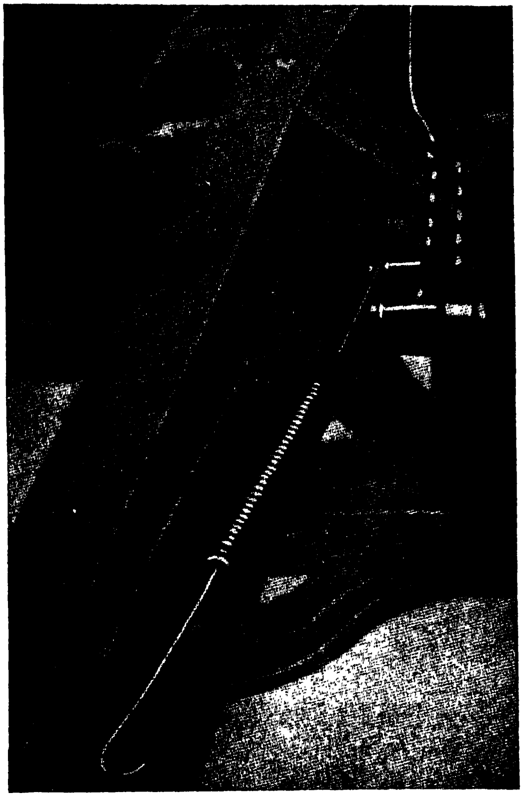


Fig. 139 — Clutch assister spring

of the driven disc during the time the clutch is engaged. Under such circumstances these two surfaces "slip" over one another, with the result that a much decreased proportion of the power from the engine is carried through to the transmission. Such slippage may be the result of a number of causes. Some of the most common are: (1) worn lining; (2) glazed lining (the result of constant rubbing of dust or dirt between the discs); (3) grease or oil on the lining; (4) installation of improper type of lining for the particular clutch; (5) improperly installed lining; (6) lack of free play in the clutch

pedal; (7) uneven adjustment of clutch release levers; (8) bent or sprung release shaft; (9) weak or broken pressure springs.

2. Grabbing and Chattering Clutch. — A properly functioning clutch will engage smoothly. If the clutch " grabs " during engagement, causing the car to move forward in a series of jerks — or if it vibrates and chatters during engagement — some element in the unit is functioning improperly. When these symptoms occur, their cause may be: (1) glazed or hardened lining (due to dirt and wear); (2) grease on the lining; (3) a bent or tight release shaft; (4) splines of the driven plate hub tight on the splines of the clutch shaft; (5) a cracked or damaged pressure plate; (6) too much play between gears; or (7) worn bearings in the transmission or rear axle.

3. Dragging Clutch. — When the pedal is thrown out to disengage the clutch, the driven plate may not stop rotating. This is called dragging. Dragging may be caused by: (1) too much pedal free play; (2) improper release-lever adjustment; (3) a warped driven plate; (4) tight or burred splines.

4. Rapid Wear of Lining. — Too rapid wear of the clutch lining may be caused by: (1) insufficient pedal play (causing a slight amount of slipping); (2) the operator of the car " riding " the pedal or engaging the clutch slowly to start the car in second or high speeds; (3) weak or broken pressure springs, incapable of squeezing the pressure plate tight enough against the driven plate; (4) badly warped pressure plate; (5) incorrect or improperly installed lining.

5. Clutch Noises. — Noises caused by worn bearings in the transmission and rear axle can sound as if they were coming from the clutch and care must be taken, therefore, before assigning a particular unusual noise as coming from the clutch. Noises actually arising from an engaged clutch, however, can be caused by: (1) poor alignment between the clutch or transmission housing and the engine; (2) worn splines on the clutch shaft and driven plate.

When the clutch is disengaged, noises can be caused by: (1) worn or dry release bearing; (2) worn or dry pilot bearing in the flywheel; (3) binding or tight release bearing.

Clutch Adjustments. — On most clutches there are only three adjustments to be made, two of which can be made without removing the clutch from the car — the other only after the clutch assembly has been removed.

1. Floorboard Clearance Adjustment. — This adjustment is accomplished by means of a screw located near the lower end of the clutch pedal, and is designed to prevent the pedal arm from resting against the floor board when the clutch is engaged.

2. **Free-Play Adjustment.** — This adjustment is accomplished by another adjusting screw located near the lower end of the clutch pedal arm. This screw should be set so that a small amount of free play remains in the pedal after the clutch has been engaged. This free play will insure the clutch being fully engaged and will eliminate any possibility of slipping.

3. **Clutch Release-Lever Adjustment.** — This adjustment should be made every time the clutch is removed from the car, and can be made only at such times. A clutch rebuilding machine equipped with a dial gage, or a gage plate, is used for making this adjustment to factory specifications.

To remove the clutch assembly, the transmission must first be removed. To remove the transmission from a car with a torque-tube drive, it is necessary to slip the rear-axle assembly, wheels and all, back out of the way.

On a car with the Hotchkiss Drive, it is necessary only to " split " the universal joint, drop the propeller shaft and remove the transmission.

When replacing the clutch assembly, it is necessary to use a pilot or a spare clutch mainshaft to line up the hole in the driven disc hub with the pilot bearing hole in the flywheel. This is necessary so that, when the transmission is replaced, the main clutch shaft will slip through the splines in the clutch driven plate hub and into the pilot bearing.

On newer cars the release bearing has its lubricant sealed inside, and should require no attention for its lifetime. The pilot bearing can be lubricated only when the clutch has been removed. The pedal shaft has nipples for greasing the shaft each time the car is greased.

CHAPTER XXI

POWER TRANSMISSION — THE TRANSMISSION

Purpose. — To start a motor vehicle from rest, the inertia of its whole weight must be overcome. A high percentage of all the power the engine has is necessary to do this. If the gasoline engine could develop full power in turning the crankshaft slowly as can a steam engine, it would be feasible to transmit the power directly to the rear wheels even in starting. But the gasoline engine does not develop its full power when it is running slowly. It has to be working fairly fast before it develops anything like maximum power and torque.

Since much power is needed in starting, in climbing a hill, and in pulling a load whatever the car speed, a means must be supplied to permit the engine crankshaft to revolve at the relatively high speed which necessarily results from production of the desired power while the wheels turn at slower speeds. This is accomplished by a set of gears called a transmission or gear set, which, in addition to performing the function described, itself multiplies the torque as explained in Chapter III.

Typical Designs. — To secure flexibility of operation, transmissions in modern passenger cars are provided with three forward speed ratios and one reverse ratio. The car driver may select any one of these ratios at will by operation of a gearshift lever, usually located on the steering column beneath the steering wheel. (Transmissions of trucks and buses usually are provided with four or more forward speeds and reverse).

The three forward speed ratios are known as " low " or first, " second," and " high " or third. In high gear the clutch and transmission shafts are locked together so that the power flows from the engine through the clutch and transmission to the propeller shaft without reduction of speed, and the speed ratio of the high gear, therefore, is 1:1. As the power flows through from the propeller shaft and on through the ring gear and pinion of the rear axle, however, the speed is reduced in a ratio of about 4:1 in American passenger cars. Thus, even in high gear, the rear or driving wheels revolve only about one-fourth as fast as does the engine crankshaft. In second gear, the speed reduction in the transmission is such that

the speed ratio is roughly about 1.6:1, making a total engine-to-rear-wheel speed reduction of about 6 or 7:1. In low gear the speed ratio in the transmission is about 2.5:1, making the total reduction about 10:1. The speed ratio in reverse gear is either the same or higher than that in first gear. When an overdrive is used, a fourth forward speed ratio is provided; in this case the engine crankshaft speed is

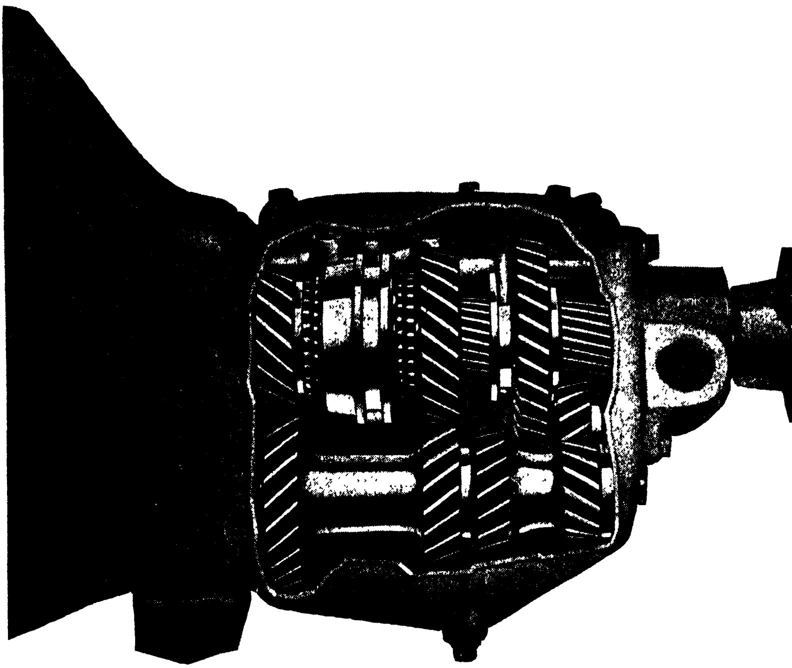


Fig. 140 — Three-speed and reverse transmission with synchronizing mechanism

less than that of the propeller shaft — usually about 72% of the propeller shaft speed. Overdrives will be described in detail in a following section.

Fig. 140 shows a three-speed, all-helical-gear, "synchromesh" transmission that is typical of American passenger-car transmissions. Such a transmission also is classed as "selective" because the driver can select the desired gear by movement of the gearshift lever. The main-drive and second-speed gears are of the constant-mesh type, that is, their teeth are always in contact; only the shifts to first speed and reverse are made by shifting the reverse and low sliding gear on the mainshaft. Shifts are made to second and high gear and vice-versa by means of sliding jaw clutches called "dogs," which are slid along the mainshaft until the jaws or teeth on the

dog mesh with those in the hub of the gear selected. A synchronizing mechanism acts to slow down the faster moving of two gears to be engaged until the two gears are revolving at the same speed so that they can be engaged quickly, noiselessly, and without clashing. Details of this synchronizing mechanism and the action of the sliding jaw clutches or dogs will be given later in this chapter.

Transmissions in American passenger cars are the same type as shown in Fig. 140, except that some have the main-drive, first-speed, and second-speed gears of the constant-mesh type; some have spur-type gears for first speed and reverse; and some have a different arrangement of gears. In addition, transmissions with four forward speeds and reverse have appeared from time to time in higher priced passenger cars. Trucks and buses may use five, six, or seven forward speeds in one unit.

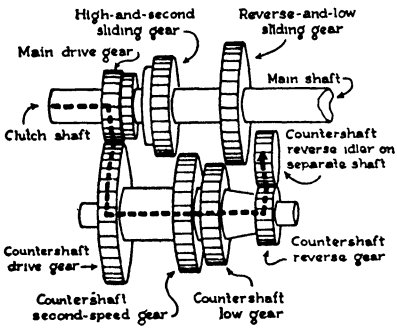


Fig. 141 — Principal parts of transmission and flow of power in neutral

The typical three-speed-and-reverse, helical-gear, synchromesh transmission shown in Fig. 140 is made up of three main parts: the **case,** the **rotating parts** with their bearings, and the **shifting mechanism.**

The case is generally of cast iron and is usually bolted directly to the rear of the clutch housing. The case cover usually carries the shifting mechanism and seals the transmission against dirt and water. The case acts as a container for the bath of oil in which the gears operate; it is fitted with filler and drain plugs for the lubricant, a breather to take care of air expansion caused by heating, and sealed mountings for the bearings which carry the shafts.

The shafts and gears shown in Fig. 141, plus the bearings, jaws, and synchronizing mechanism make up the rotating parts. It should be noted that Fig. 141 and Figs. 142–145 have been simplified considerably to show the flow of power clearly. Usually all gears are helical instead of the spur type shown, and the second-speed mainshaft gear itself does not slide. The relation of these parts and the flow of power during the different shift positions will now be discussed.

When the transmission is in "neutral," it means simply that the flow of power is cut off in the transmission so that rotation of the **clutch shaft is not transmitted to the mainshaft.** This condition

permits the engine to be started and to run without the car itself being put into motion. Fig. 141 shows how this condition is carried out when the gearshift lever has been moved to the neutral position. As shown by the dotted line, power flows from the clutch shaft to the countershaft through the main drive gear and countershaft drive gear which are constantly in mesh and keyed to their respective shafts. Although the mainshaft and countershaft second-speed gears also are constantly in mesh in the actual transmission, no power is transmitted by these gears because, since the second-speed sliding clutch or " dog " is not engaged, the main second-speed gear is not keyed or splined to the mainshaft and, consequently, rotates idly on it. Since the reverse-and-low sliding gear on the mainshaft is not in mesh with either the countershaft low-gear or the reverse-gear idler in this position, the engine merely turns the main drive gear, the countershaft cluster, and the reverse idler. The mainshaft is a part distinct from the clutch shaft. Its forward end is free, except in high gear, to rotate within a bearing mounted at the rear of the clutch shaft.

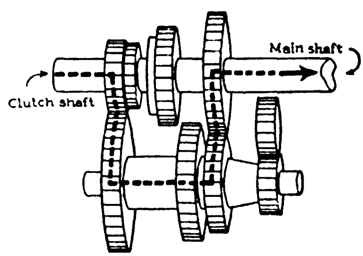


Fig. 142 — Flow of power in low gear

The shift from neutral to low gear consists in sliding the reverse-and-low sliding gear to the left until its teeth mesh with those of the countershaft low gear by moving the gearshift lever to the low position. The flow of power in low gear is shown in Fig. 142. The clutch shaft drives the countershaft through the main drive gear and countershaft drive gear. As in neutral the second-speed gears are in mesh in the actual transmission, but transmit no power, and the power flows from the countershaft to the mainshaft through the countershaft low gear to the reverse-and-low sliding gear which is splined to the mainshaft, thence to the universal joint on to the rear wheels. In low gear the mainshaft revolves only about 1/2.5 as fast as the clutch shaft is revolving. This reduction in speed is accomplished by driving from small to large gears on two sets of gears.

In shifting from first to second gear, the reverse-and-low sliding gear is first slid out of mesh with the countershaft low gear into its neutral position as shown in Fig. 143. The sliding jaw clutch or " dog " located between the main drive gear and the mainshaft second-speed gear in the actual transmission has been moved to the right so that its teeth mesh with the teeth on the hub of the second-

speed gear. Since the sliding " dog " is splined to the mainshaft, the second-speed gear is now splined to the mainshaft and transmits power. As shown in Fig. 143, the power flow is now from the clutch shaft to the main drive gear to the countershaft drive gear, through the countershaft to the countershaft second-speed gear to the mainshaft second-speed gear which turns the mainshaft. The speed reduction from clutch shaft to mainshaft is not as great as it is in low gear because the gear ratio of the second-speed gears is less.

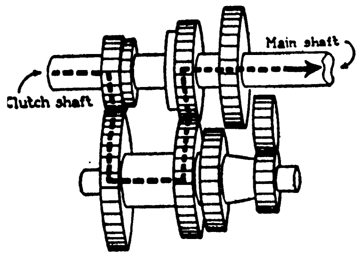


Fig. 143 — Flow of power in second gear

Fig. 144 shows the flow of power in high gear. By moving the dog from the position where its teeth are meshed with those of the hub of the second-speed mainshaft gear through its neutral center position to the left until its teeth mesh with those of the main drive gear, the second-speed gear is taken out of engagement and the mainshaft is locked to the clutch shaft. The drive is straight through as shown in Fig. 144 — the mainshaft revolves at the same speed as does the clutch shaft. Although all the gears rotate, they transmit no power.

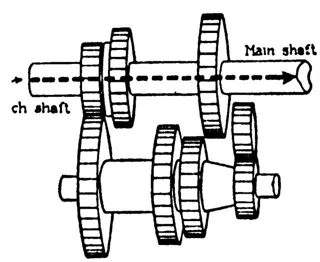


Fig. 144 — Flow of power in high gear

In reverse, shown in Fig. 145, the sliding clutch or dog is in the neutral position, breaking the connection between the clutch shaft and mainshaft. The reverse-and-low sliding gear has been slid to the right until it meshes with the reverse idler. The second-speed gears revolve but transmit no power. The power is transmitted from the clutch shaft to main drive gear to the countershaft drive gear, through the countershaft to the countershaft reverse gear, to the reverse idler which reverses direction of rotation, to the reverse-and-low sliding gear to the main shaft and thence to the rear wheels. The reduction in speed from the clutch shaft to the mainshaft usually is the same or a little more than that obtained in low gear. It is obtained, of course, in driving from small gears to large gears on two sets of gears.

When helical gears are used for the reverse-and-low sliding gear, reverse gears, and low gear, the mainshaft splines on which the re-

verse-and-low sliding gear is moved along the shaft must also be helical, as shown in Fig. 140. This design is necessary in order that the reverse-and-low sliding gear be slid easily into mesh with the countershaft low gear and reverse idler, and so that the gears do not tend to slip out of mesh because of the angle of the teeth.

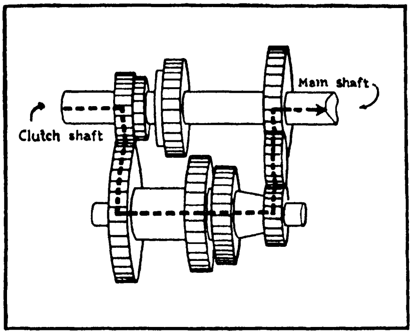


Fig. 145 — Flow of power in reverse

The synchronizing mechanism, as previously stated, acts to slow down the faster rotating of two gears to be meshed so that they are quickly made to revolve at the same speed. At this time they can be meshed without clashing or grinding without waiting for the faster-rotating gear to slow down by itself. Synchromesh is provided for second and high constant-mesh gears on all passenger-car transmissions, and also for first gear on some. It generally is not considered as necessary for low or reverse gears since they usually

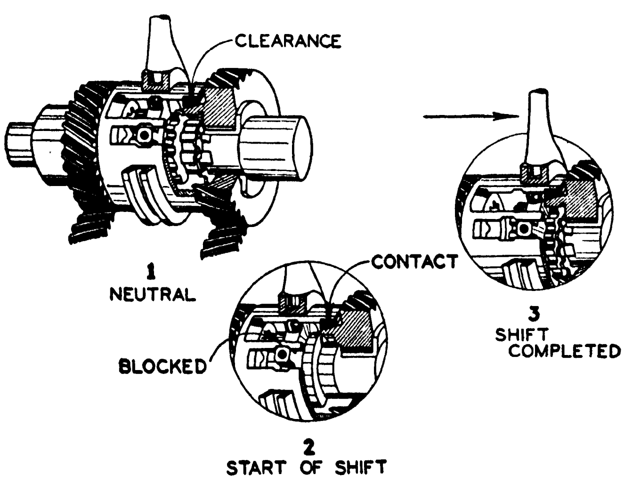


Fig. 146 — Operation of synchronizing mechanism

are engaged when the car is stationary. As shown by Fig. 146 it consists essentially of a cone clutch or synchronizing drum which acts as a brake on the faster-revolving gear, and a spring or other means for reducing the pressure on the cone clutch after the gears

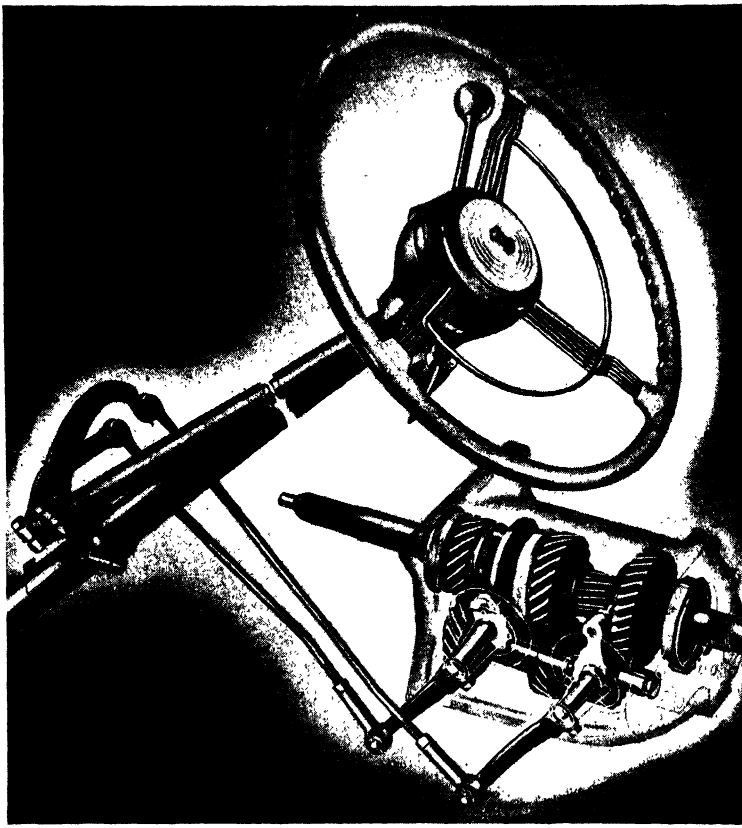


Fig. 147 — Typical gearshift operating mechanism and transmission

are synchronized, to permit the gears to be shifted easily. Although synchromesh mechanisms used in various passenger cars vary somewhat in design, the general principles given apply in all cases.

The type of gearshift operating mechanism shown in Fig. 147 is practically universal in American passenger cars. The gearshift lever is mounted on the steering column. Shifts are made by moving the gearshift lever to the desired position. When the lever is moved to all possible positions, it traces the pattern of the letter H laid on its side. The neutral position is in the center of the H. When the lever is pulled back toward the driver in its upper position, the

motion is transmitted down one of two concentric tubular rods located alongside the steering column and connected to the upper crank shown in Fig. 147 which is linked to the first and reverse sliding gear. It can be seen by the arrangement of the linkage that this motion of the gearshift lever moves the first and reverse sliding gear to the left until it meshes with the low gear on the countershaft. When the gearshift lever is moved to its farthest position from the driver in the upper position, the tubular rod, upper crank, and linkage move the first and reverse sliding gear to the right until it meshes with the reverse idler. When the gearshift lever is moved down through neutral and then pulled back toward the driver, the first and reverse sliding gear is first locked in neutral, the gearshift lever is engaged with the other tubular rod alongside the steering column which is connected with the lower crank shown in the illustration. This lower crank is linked to the dog between second and high gear so that the motion of the gearshift lever slides the dog into contact with the internal teeth on the main drive gear, and the transmission is in high gear. Moving the gearshift lever to a position farthest from the driver in its lower position, in turn, shifts the dog to the right until its teeth mesh with those of second gear.

Shifting Mechanism. — The shifting mechanism inside the transmission usually consists of various arrangements of shifter rails to which are connected shift forks or yokes connected to the sliding gears or dogs. The rails usually are locked in their low, second, high, reverse, or neutral positions by means of balls under spring pressure which slip into notches in the shifter rails, as shown in Fig. 148. The arrangement is such as to prevent more than one gear to be engaged at one time. The gearshift linkages used in various passenger cars, although similar in principle to the one just described, differ considerably in detail. Some use a cable instead of a rod for selecting gears, but all shift by means of a rod. In cars produced before 1937, the gearshift lever projecting vertically upward from the center of the floor of the front compartment was used practically universally. In cars produced in 1941, it had been completely replaced by the steering-column-mounted type just described.

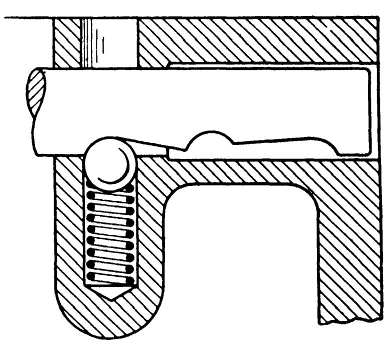


Fig. 148 — Typical shifter rail arrangement

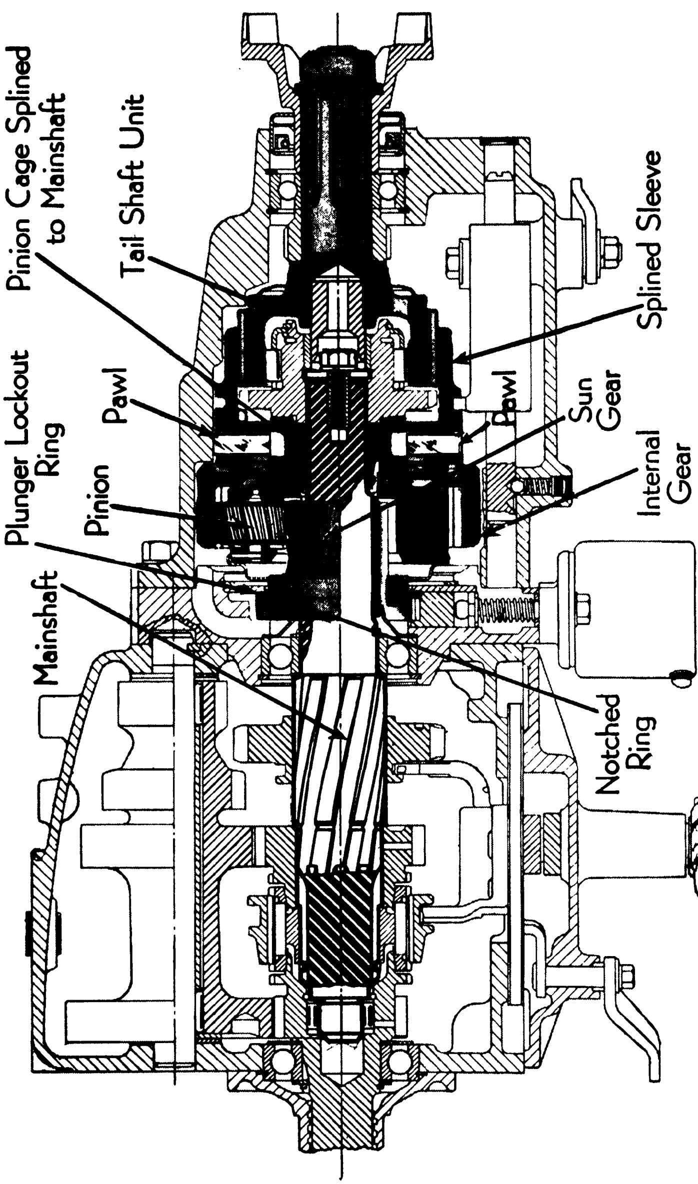
Although transmissions with four forward speeds and reverse provide the greatest number of gear changes ever found in passenger cars, four or five forward speeds are commonly found, and six or seven forward speeds are occasionally found, in a single transmission unit in trucks and buses. The number of forward speeds employed in trucks or buses usually depends upon the size of the vehicle and the road conditions, load and speeds under which they must be operated. By the use of " two-speed axles " or two interconnected or " compounded " multispeed transmissions, the number of possible forward speeds can be multiplied to produce 10 or 12 possible forward speeds so that the engine can be kept functioning at top speed and efficiency under a wide range of operating conditions. For some cases, when a four-speed transmission is used, the low-gear position, which provides an unusually high gear ratio, is employed only for very severe starting or climbing conditions. The gearshift arrangement employed, of course, must differ somewhat from the conventional. In one arrangement second, third, fourth and reverse speeds are used in the conventional H shift for average driving conditions. For severe conditions, when it is desired to use first speed, a special latch is used to make the shift.

Overdrives. — A method of obtaining a fourth forward speed employed extensively in modern passenger cars is the use of an " overdrive." It is so called because it provides a speed ratio " over " that of direct or high-speed ratio. This device permits the engine to operate at only about 72% of the propeller-shaft speed when the car is operating in the higher speed ranges. Because the engine is not required to turn over as fast at high car speeds when it is in high gear, the use of overdrives reduces engine wear and vibration, and saves gasoline. Overdrives usually are employed to supplement conventional transmissions, and are bolted to the rear of the transmission between the transmission and the propeller shaft. Usually a slightly higher rear-axle gear ratio is employed with an overdrive than without one.

In the most commonly used designs, the shift to overdrive can be made when the car is traveling above a predetermined speed (usually from 18 to 35 mph) by lifting the foot momentarily from the accelerator. The operation of the overdrive is controlled by a centrifugally operated switch. When the car slows down below another predetermined speed (usually slightly lower than the cut-in speed), the car returns to third speed automatically in most designs. When greater power and acceleration are required than can be furnished through the overdrive gear ratio, such as when passing a car

on the road, the car can be shifted back to direct gear when in overdrive by depressing the accelerator past the full-throttle position.

Fig. 149 shows a design of overdrive in common use in American passenger cars. It consists essentially of a " planetary " gear set, a key operated by a solenoid and a spring for holding the " sun gear " stationary, and centrifugally operated pawls that permit the overdrive to be cut in or out at the desired speeds. The planetary gear set is made up of a sun gear, three pinions or " planets," and an internal gear, assembled and meshed as shown. Gears are of the helical constant-mesh type. The three pinions are mounted in a cage that is splined to the transmission mainshaft. When the car is in direct drive (overdrive not in operation) the sun gear is held stationary by the key inserted in a slot in its collar. The locking of the sun gear causes the pinions to rotate around it, thus causing the internal gears to rotate faster than does the transmission mainshaft. In direct drive, however, the faster-moving internal gear transmits no power as the centrifugally operated pawls do not engage the internal gear with the tailshaft sleeve. The drive in direct gear is straight from the mainshaft to the tailshaft through the free-wheeling unit (to be described later). When the driver desires to enter overdrive when the car is above the cut-in speed, he lifts his foot momentarily from the accelerator, which permits the pawls to engage slots in the tailshaft sleeve, thus locking the internal gear to the tailshaft. The unit is now in overdrive as the tailshaft is moving faster than the mainshaft. Below the cut-in speed the driver cannot enter overdrive because the pawls are held in their inward position on the internal gear by coil springs, and will not engage slots in the tailshaft sleeve until the speed is such that the centrifugal force of the pawls overcomes the pressure of the springs. The unit may be returned to direct drive when the speed is below the cut-in speed by permitting the springs to draw the pawls from the tailshaft sleeve by momentarily lifting the foot from the accelerator. The accelerator may be released specifically for this purpose, or in slowing down in normal operation. To return the car to direct drive at any speed, the driver presses the accelerator past the full-throttle position. This action energizes a solenoid which pulls the key from engagement with the collar of the sun gear after the ignition has been cut for a few explosions. As the sun gear is now free to rotate idly, the pinions do not rotate around their axes, and the whole unit revolves at the same speed as does the mainshaft. Thus the car is in direct drive and the overdrive is not in operation. When it is desired to return to overdrive, the



(Courtesy MoToR Factory Manual)

Fig. 149 — Planetary type of conventional overdrive

foot is removed momentarily from the throttle and a spring inserts the key in the sun-gear collar, holding it stationary.

Other types of overdrive differ in their method of control. In one well-known design, the centrifugal pawls that engage or disengage the internal gear and tailshaft are omitted, the internal gear and tailshaft being attached together. All changes from overdrive to direct and vice-versa are effected by inserting and removing the key from the collar of the sun gear. A centrifugal switch operates in connection with the solenoid and spring to control the speed at which the key may be inserted by the solenoid or withdrawn by the spring. The emergency method of returning to direct speed from overdrive when above the cut-in speed is the same as that described previously.

Most commercial overdrives include a " free-wheeling " unit which is effective *only* when the overdrive is not in operation and when the overdrive unit is not locked in direct drive. This lockout is provided to render the free-wheeling unit and overdrive inoperative during certain driving conditions, such as when going down steep hills when it is desirable to use the compression of the engine as a brake. To lock the overdrive out, the driver usually must pull out a lockout knob on the instrument board.

When the " free-wheeling " unit is in operation, the engine can drive the car, but the car cannot drive the engine. When the momentum of the car tends to drive the engine, as when slowing down, the free-wheeling action comes into play and disconnects the engine, clutch and transmission from the remainder of the power-transmission line. When the speed of the car falls below the corresponding speed of the idling engine, however, the engine again drives the car.

The free-wheeling unit, often called an " overrunning clutch," usually consists of a driving member, driven member, and rollers arranged so that the driving member can drive the driven member but, when the driven member attempts to drive the driving member, the driven member turns free and no power is transmitted to the engine.

The free-wheeling feature of overdrives itself is claimed to account for some of the fuel saving effected by overdrives. Free-wheeling also permits gearshifts from first to second, from second to high, from high to second, and from second to first to be made without the use of the clutch, by removing the foot from the accelerator. This is possible because the release of the accelerator puts the car into free-wheeling, disengaging the engine, clutch, and transmission from the remainder of the drive.

Special Developments. — Recent developments in transmissions

all follow the same trend — either to take over completely from the driver, or to assist him in, the job of making gearshifts. Most of them also offer smoother car operation. Mechanisms of this type have become more and more common in recent years. Following are descriptions of some of the more common types in use:

Vacuum-Operated Gearshifts. — Fig. 150 shows the arrangement of a transmission provided with a gearshift mechanism in which the

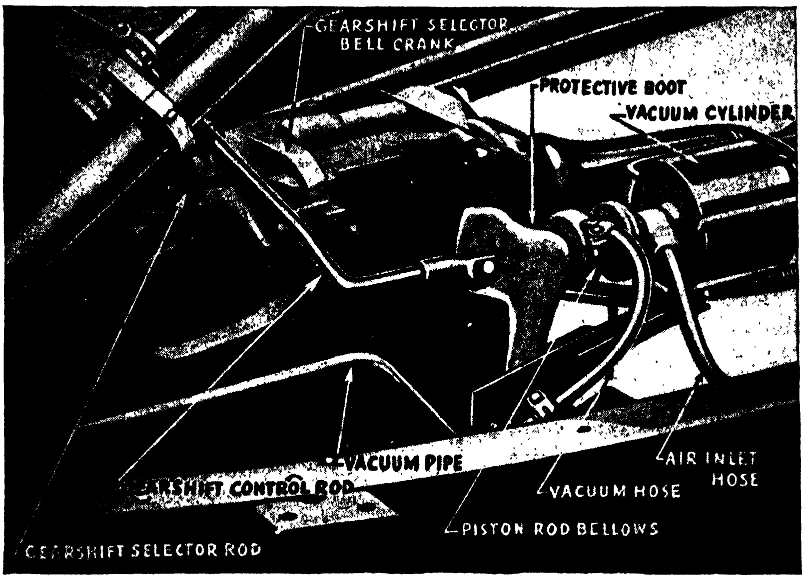


Fig. 150 — Vacuum-operated gearshift

driver shifts the gears by moving the shifting lever just as in conventional shifting mechanisms, but practically no effort is required to make the shifts as the actual work of shifting the gears in the transmission is done by a vacuum cylinder. Movement of the shifting lever to one of its positions opens or closes the control valves for the vacuum cylinder which admit or cut off vacuum or atmospheric pressure. The cylinder contains a piston which can be moved in either direction to shift the gears into the position indicated by the position of the shifting lever. If, for any reason, the vacuum-operated mechanism will not function, provision is made for the gears to be shifted manually.

Fluid Flywheel. — Fig. 151 explains graphically the principles of the fluid flywheel. The device is used either with a conventional clutch and transmission, with or without overdrive; or as a part of an automatic transmission in which case it replaces the clutch. The

fluid flywheel consists essentially of two identical rotating members as shown. The driving member acts as a simple centrifugal pump which delivers oil to the driven member or centrifugal motor. Either unit may be the pump and the other the motor, depending upon whether the engine is driving the car, or vice-versa. Each member has a number of radial vanes which form curved radial passages around which the oil travels. Both members are mounted inside

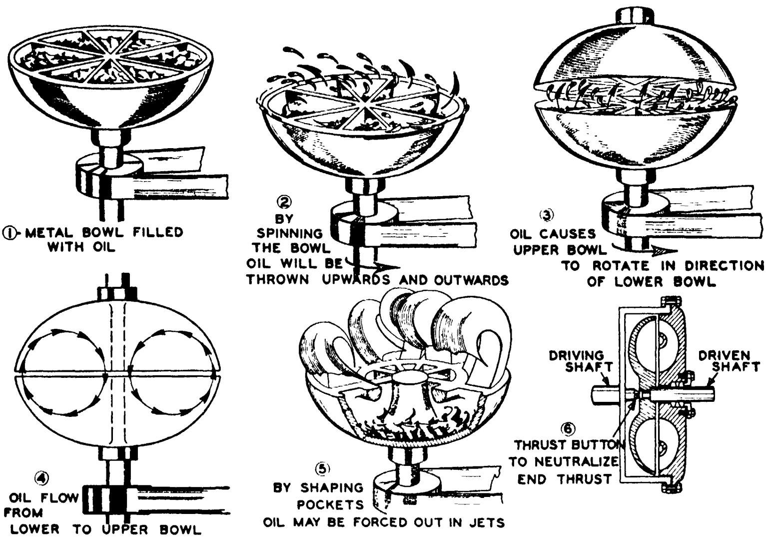


Fig. 151 — Fluid flywheel operating principles

an oil-filled or partially oil-filled welded-steel housing. When the fluid flywheel is in operation, the oil is driven toward the outer rim of the faster-moving driving member by centrifugal force, is thrown across to the driven member, from whence it travels around back to the driving member, thus completing the circuit. The difference between the speeds of the two members, of course, is the slip and, the greater the slip, the faster the oil travels around the liquid flywheel circuit. As the amount of slip is determined by the torque required by the driven member, the slip, of course, is 100% with the car stationary, but drops quickly as the car gathers speed. In some arrangements, it is less than 1% during level cruising above 30 mph. Where the fluid flywheel is installed with a conventional clutch and transmission with or without overdrive, it is recommended that the fluid flywheel be used instead of the transmission for starting either in second or in high gear when operating in fairly level country. When used as a part of an automatic transmission, such as the one

described in the following paragraphs, the fluid flywheel sometimes replaces the clutch. An important advantage of the fluid flywheel is the smooth, jerkless acceleration that it effects because of the cushioning action of the fluid medium between the two members. It cannot, however, transmit torques greater than that of the engine as can some types of hydraulic transmissions.

"Hydra-Matic Drive." — This is a fully automatic drive. As shown in Fig. 152, it combines a four-speed forward and reverse automatic geared transmission in front of which is a fluid flywheel as just described. The geared transmission consists of three sets of constant-mesh helical planetary gears placed in series. The two planetary gear sets on the left provide the four forward gear changes, and the one on the right is used for reverse. The fluid flywheel acts to cushion the impact of the automatic shifts, as well as to damp the torque reactions of the engine. No clutch pedals are provided in cars equipped with this drive, control being accomplished entirely by accelerator and brake.

The planetary gear sets of the automatic transmission are placed in series so that power may be transmitted through either or both of the sets to produce any of the forward speeds or reverse. A centrifugal governor incorporated in the transmission selects the proper gear for each speed and throttle position. The change from one gear to another is accomplished through hydraulically operated pistons, in some cases assisted by springs, which control brake bands on the planetary gear sets and clutches within the planetary unit. The speed at which the various shifts occur is governed by throttle position as well as by the centrifugal governor so that, as the throttle is opened, the gears shift at higher and higher speeds. This feature permits maximum power and acceleration when most needed.

When the " Hydra-Matic Drive " is in low gear, as shown in Fig. 152, the brake bands of both planetary gear sets to the left are held against their drums and power is transmitted from the fluid flywheel casing through one planetary gear set through the fluid flywheel and then through the second planetary gear set to the output shaft and propeller shaft as indicated. The total speed reduction is 3.658:1. Driver control is provided by a lever and sector segment mounted on the steering column beneath the steering wheel which can be adjusted to any one of four positions: neutral, high, low, and reverse. In the " high " position the transmission shifts automatically for any one of the four forward speeds. The " low " position is for hill-climbing or heavy or muddy terrain; only first and second gear positions are provided.

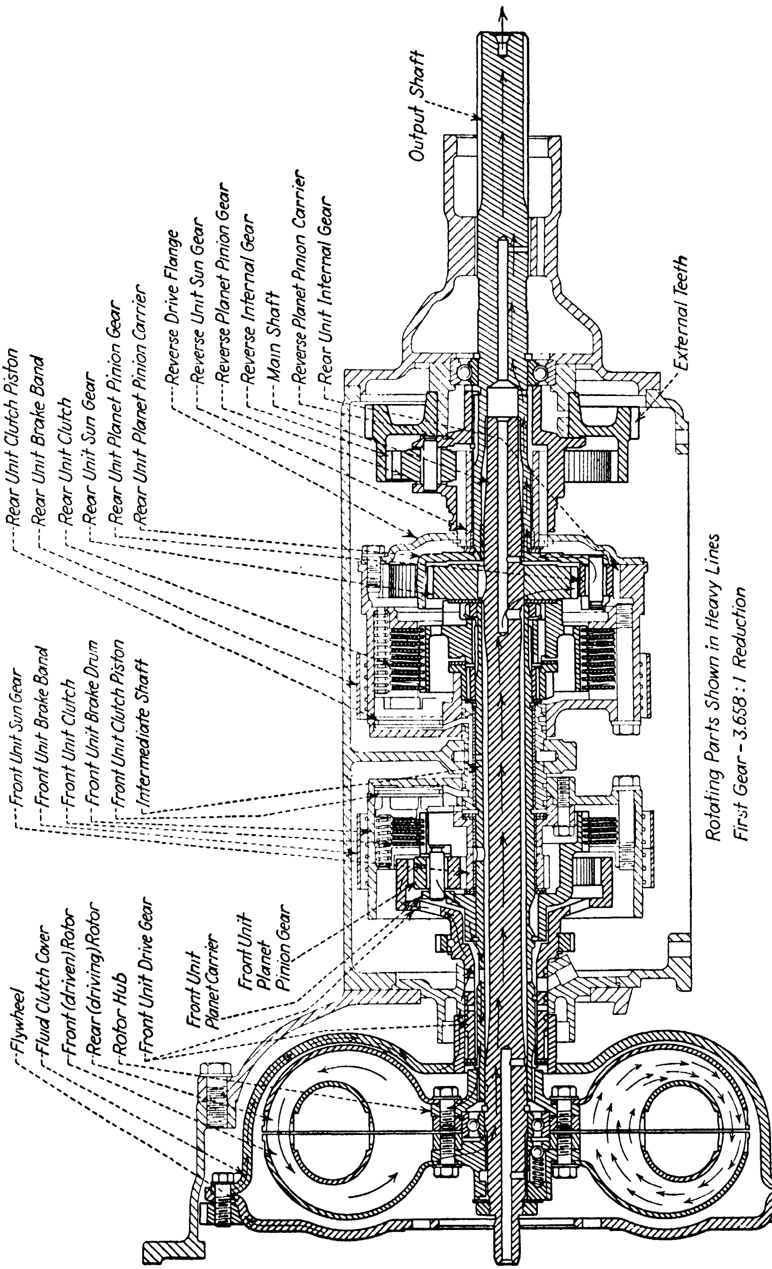
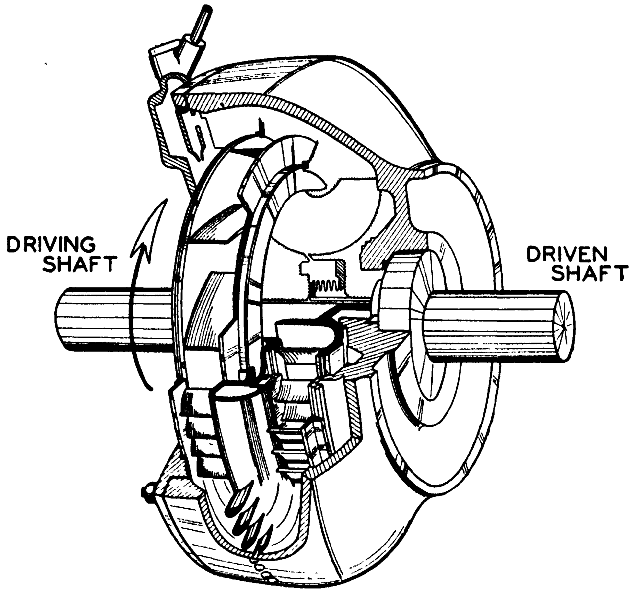


Fig. 152 — "Hydra-Matic" automatic transmission — Flow of power in first gear



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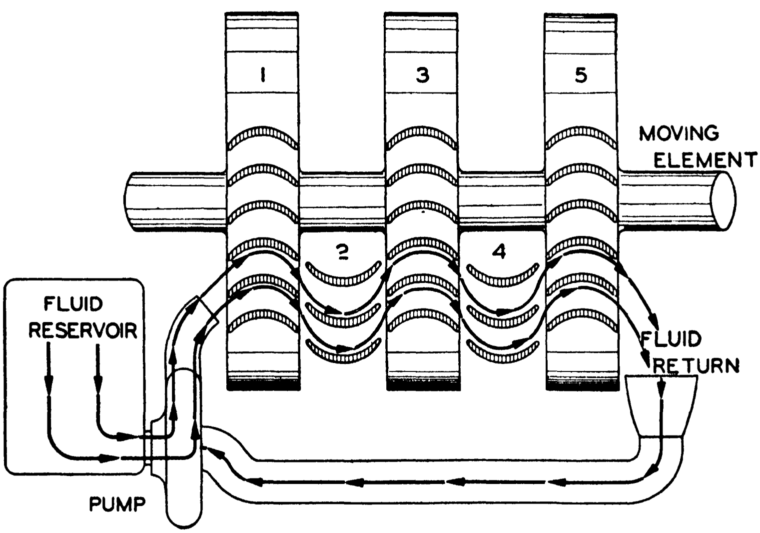


B

Fig. 153 — Turbine of automatic hydraulic transmission or torque converter

Torque Converters. — A fully automatic hydraulic transmission or torque converter that is used in buses provides multiplication of the engine torque up to 5:1 during starting. This hydraulic transmission comprises essentially a turbine, a friction clutch for disconnecting the engine from the turbine, a reverse gear, and a roller clutch which disconnects the turbine from the output shaft when in direct drive. The turbine, shown in Fig. 153*A*, consists of a centrifugal pump wheel driven by the engine; a three-bladed, three-stage rotor wheel connected to the propeller shaft; and a casing with stationary blades interposed between the rotor blades. This " staging " of the rotary blades between stationary blades, shown in Fig. 153*B*, is the reason why the torque converter can multiply the torque.

" Underdrive " Semi-Automatic Transmission. — This is a four-speed forward and two-speed reverse geared semi-automatic transmission (Fig. 154) used in conjunction with a fluid flywheel and a

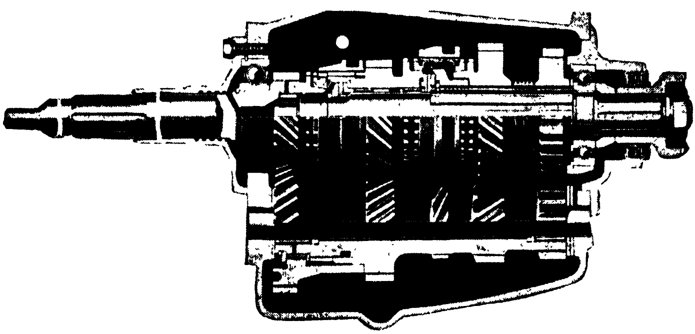


Fig. 154 — Four-speed semi-automatic geared transmission

conventional clutch. It was introduced as special equipment on some 1941 models. All gears are helical except those used for reverse. Instead of the usual four positions, the gearshift lever has but three: " high," " low," and " reverse." In a car provided with such a drive, most of the driving can be done with the gearshift lever in the high position — including starting, cruising, and stopping — because of the action of the fluid flywheel and the semi-automatic nature of the transmission.

With the gearshift lever in the high position the transmission can be shifted back and forth from third gear (1.55:1) to fourth gear (1:1) in the same manner as the shift is made between third speed and overdrive in cars so equipped. That is, the car is started in third gear and stays there until the driver releases the pressure on the accelerator pedal when the car speed is over 15 to 17 mph. At

this time the transmission is shifted to fourth gear by the action of a vacuum unit connected to the engine manifold. When a burst of speed or extra power is needed, pushing the accelerator past the full-throttle position energizes a solenoid which acts to shift the transmission back to third gear (providing the car speed is below 53 mph). When the car speed drops below 13 to 15 mph with the transmission in fourth gear, the position of the centrifugal governor causes the transmission to be shifted automatically back to third gear.

Use of the low position of the gearshift lever is recommended only for steep hills, mud, sand, gravel, or rough terrain. When operating in this range, shifts between first and second are made in exactly the same way as those between third and fourth when the gearshift lever is in the high position. The shift to second gear can be made when a speed of 8 mph has been reached. The ratio in first gear is 3.07:1; in second gear, 1.98:1.

The conventional single-plate clutch is used only for shifting in and out of reverse, for engaging the gears after the gearshift lever has been in the neutral position, and when shifting the gearshift lever with the car in motion. The transmission is provided with a free-wheeling unit which is operative only in first and third gears.

Transmission or Gear Box Service. — Transmission troubles and their causes and remedies can best be discussed under six main headings as follows:

1. Noise When Transmission Is in Neutral. — If the transmission is not aligned with the engine so that there is no binding along the shaft from the flywheel to the transmission, a constant grinding noise will be heard. This noise can be eliminated by checking the alignment of both the clutch and transmission housings, after the transmission has been removed, and correcting any misalignment found.

A hum or howling will be heard when bearings or bushings are worn or in need of lubrication; when a shaft is sprung, worn, or in need of lubrication; when gears are chipped, burred, not matched, improperly machined, or in need of lubrication; when there is too much backlash throughout the gear train; when too much end play exists in the countershaft or gears; or when gearshift forks rubbing in grooves cause gear interference.

2. Noise When Transmission Is in Gear. — The noises heard in neutral will also be heard in gear, but will be more pronounced. In gear, the main transmission shaft rear bearings will howl if dry. Noises originating in the rear end and clutch may also seem to come from the transmission.

3. Hard Shifting; Sticking in Gear. — When a transmission is hard to shift or when it sticks in gear, the difficulty may be due to one of several causes. Improper clutch adjustment may be preventing the clutch from releasing all the way; splines on the transmission shaft may be burned or distorted; shifter lock springs may be too strong; gear teeth may be battered; the silent-shift unit may be binding; or the remote-control unit may be out of adjustment.

4. Slipping out of Gear. — Causes of the transmission slipping out of gear include improper transmission-engine alignment; too much clearance between teeth in mesh; worn gears or bearings; weak or broken shifter lock springs; insufficient mesh of gears; and improper adjustment of remote-control linkage.

5. Oil Leaks. — Oil leaks may result from too high an oil level; damaged or improperly installed gaskets or oil seals; loose cover bolts; or cracked transmission case or cover.

6. Vacuum Shift Control. — If the vacuum shift control is to function properly, there must be no leakage in the tubing from the intake to the manifold. Connecting linkage must work freely and be in proper adjustment.

The first five of the troubles just listed are common to all transmissions and can be classified as misalignment of parts, lack of lubrication, poor adjustment, or wear.

In practically every case, it is desirable to remove the transmission assembly and separate all the parts, noting the condition of each as it is removed. Then, each part should be washed in gasoline, thoroughly tested, and inspected for fit and wear. Finally the unit should be re-assembled according to manufacturer's specifications, new parts being installed where necessary.

If a transmission "howl" due to lack of lubrication is noticed immediately and lubricant applied at once the chances are that no damage will have been done.

Overdrive and free-wheeling units with their different types of control should be kept properly lubricated and adjusted. Before attempting to dismantle the overdrive, free-wheeling, "Hydra-Matic" drive, or other special units, it is necessary to have the car manufacturer's service manual as a guide for correct order of disassembly and assembly, as well as for all specifications.

CHAPTER XXII

POWER TRANSMISSION — THE PROPELLER SHAFT AND UNIVERSAL JOINTS

From the transmission (or overdrive), the power must be delivered next to the final drive, differential, and thence to the wheels. This function is carried out by the propeller shaft and universal joints.

Because passenger-car axles are located lower than the transmission or overdrive output shafts, the propeller shaft which is used to join them must be at an angle with the horizontal. For this reason and because the rear axle moves up and down with the action of the springs while the transmission is mounted rigidly to the frame, some form of flexible joint must be used to compensate for this angularity and motion and still permit the propeller shaft to be driven by the transmission mainshaft. This flexible joint is called a universal joint. The principle of operation and construction of universal joints was explained in Chapter III. The propeller shaft itself is usually made of hollow steel tubing which construction gives light weight and torsional strength.

Fig. 155 shows the assembly of propeller shaft, two universal joints, and a slip joint usually employed when the Hotchkiss-drive construction is used. In this type of drive, the forward thrust re-

Fig. 155 — Propeller shaft, universal joints, and slip joint used with Hotchkiss drive

sulting from revolution of the rear wheels is transmitted to the frame of the car through the rear springs; it allows the springs to take the twist or torque of the driving effort. The propeller shaft is not enclosed. The function of the slip joint is to compensate for differences in length of the propeller-shaft assembly caused by changes in its angularity as the axles move up and down with the springs. For example, it is obvious that, as the propeller shaft approaches a horizontal position when the rear springs are compressed in going over a bump, the propeller shaft must become shorter, and this shortening is done by telescopic action of the slip joint. The slip joint is provided with external and internal splines free to slide one upon the other, as shown.

The other type of propeller-shaft arrangement used in American passenger cars is called the "torque-tube drive." In its construction the propeller shaft is enclosed in a "torque tube" which takes the torque action of the rear axle (taken by the springs in the Hotchkiss drive). This tube incorporates bearings which support the propeller shaft. It is bolted rigidly to the rear-axle housing and supported at the front by the transmission. Only one universal joint has been found necessary when a torque tube is used. It usually is placed between the transmission and the propeller shaft. Often "radius rods" are used to assist the torque tube to take the twist and thrust of the car drive.

Universal-Joint and Propeller-Shaft Service.—Most universal joints are made with needle bearings. Lack of lubrication is the usual cause of trouble, but little should be experienced if the car manufacturer's recommendations are followed closely. These instructions will tell the correct type of grease or heavy oil to use and how many miles a car should run before lubricating these joints.

The joint must be taken apart to pack the bearings with grease. At this time it is desirable to wash all the parts and examine them for wear. Before taking the joints apart, the adjoining spots on the yokes and drive shaft should be marked so that they may be assembled in the same positions. This precaution assures retaining the balance of the parts and eliminates the possibility of propeller-shaft "whip" and vibration. When replacing the parts, particular care should be taken with the oil seals.

With the slip-joint type of connection between the universal and the propeller shaft, the splines must be lubricated, and this is usually done through a plug or Zerk fitting on the yoke whenever the car is normally greased.

Noise in the universal joint is caused by dry or worn bushings or bearings. If the slip-joint splines are loose they will cause a rattly noise. Badly worn joint parts will cause a chatter or jerk when engaging the clutch, and eventually will damage the clutch.

The propeller shaft is carried either in a housing or without any covering. In either case, should it become sprung or bent, it will whip as it turns, with resulting damage to the universal joints. The manufacturer specifies how much bend is to be tolerated in the propeller shaft. This is measured with a dial gage with the propeller shaft resting in two V blocks.

The propeller shafts that run in housings are supported on bushings. If these are allowed to run dry, they will wear, and it is possible that both the bushing and propeller shaft must be replaced.

CHAPTER XXIII

POWER TRANSMISSION — THE REAR AXLE AND THE DIFFERENTIAL

Final Drive. — The final drive serves two purposes: It turns the power flow at a right angle from the propeller shaft to the rear axle, and it provides a speed reduction from the propeller shaft to the rear axle. In passenger cars the final drive consists of a pair of helical or spiral-bevel gears comprising a pinion connected to the propeller shaft and a ring gear connected to a flange on the differential case. There are usually between 4.5 to 5.5 times as many teeth on the ring gear as on the pinion, giving a gear ratio or speed reduction between 4.5:1 and 5.5:1. The drive pinion is usually built in-

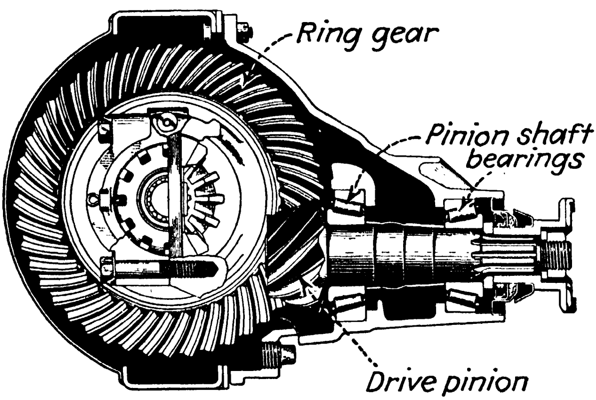


Fig. 156 — Hypoid gears used for final drive

tegral with a short pinion shaft, splined to the end of the propeller shaft or rear universal joint.

" Hypoid " gears are a type of spiral-bevel gears that are employed almost universally in the final drives of American passenger cars. As shown in Fig. 156 these gears are designed and arranged to have the axis of the pinion below that of the ring gear instead of in the same horizontal axis, as is the case with spiral-bevel gears. This type of gear was adopted principally because it enabled the propeller shaft to be lowered without decreasing the rear-axle clearance, eliminating the necessity for a " tunnel " in the rear compartment of the

car body. The pinion shaft is usually mounted in a pair of tapered roller bearings located in front of the pinion as shown in Fig. 156, or in another type of antifriction bearing. In some installations, however, the pinion is " straddle mounted " between two antifriction bearings. Due to the angle of the spiral-bevel gears, these bearings must be designed to take a thrust component. Because these gears operate under extremely high pressures and temperatures — and because of the wiping action of their teeth — special lubricants called " extreme-pressure " lubricants are used in rear axles containing hypoid gears. Provision usually is provided by means of shims or

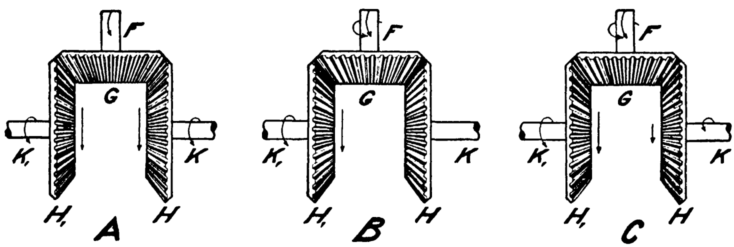


Fig. 157 — Differential action explained

screws for accurate adjustment of the position of the pinion with respect to the ring gear.

Other types of final drive found in trucks and buses are worm-gear drives, chain drives, double-reduction and two-speed drives. Worm-gear drives have the advantages of quiet operation and of permitting high speed-reduction ratios. Their construction and operation is explained in Chapter III. Two-speed final drives in effect double the number of speed ratios possible in a truck. They are controlled or shifted from the driver's compartment. Double-reduction drives provide a set of gears in addition to the spiral-bevel set just described.

Differentials. — When a car travels around a corner, the distance traveled by the outside wheels is greater than that traveled by the inside wheels. If the wheels are mounted on dead axles so that they turn independently of each other, like the front wheels on an ordinary passenger vehicle, they will turn at different speeds to compensate for the difference in travel. But, if the wheels are driven positively by the engine, a device is necessary which will permit them to revolve at different speeds without interfering with the propulsion of the car. To accomplish this purpose a system of gears called the differential is provided.

The action of the simple differential is shown in Fig. 157. At *A*

two shafts K and K_1 are attached to the large bevel gears H and H_1; and meshing with them is the pinion G, attached to the shaft F. When the shaft F is pulled forward as shown, but not rotated about its axis, the pinion G will not revolve. Since it is meshed with both gear wheels H and H_1, they will be turned about their axes, causing the shafts K and K_1 to revolve equally and in the same direction that the shaft F is being pulled. The pinion G merely acts as a connection or clutch between the two gear wheels. If the axle K is held stationary as shown at B in Fig. 157, its gear wheel H cannot revolve when the shaft F is pulled forward as before. This action causes the pinion G to roll on the gear H, revolving about its axis, while the bevel gear H_1 turns at a higher speed than before and in the same direction. This result is because H_1 is forced to revolve at the speed with which shaft F is pulled forward plus the speed imparted to it by the pinion G revolving on its own axis. If shaft K is allowed to slip a little as shown at C in Fig. 157, so that it revolves in the same direction as in condition A but not nearly so much, as indicated by the arrow, the amount that pinion G rolls on the gear H will be correspondingly reduced. Shaft K_1 will be driven as before by both the pull on shaft F and the turning of pinion G on its axis. Therefore the pinion G will not revolve as much as it did in condition B since gear H is now also turning correspondingly, reducing the amount that the shaft K_1 revolves.

This is the principle upon which all differentials are built, different arrangements of gears sometimes being used to accomplish the same result. In the differential used in passenger cars, the shafts K and K_1 are the axles to which the wheels are attached, either one of which may revolve slower than the driving speed. The revolution of the other axle then increases a corresponding amount because of the differential action of the gears.

Fig. 158 shows diagrammatically a simple bevel-gear differential. The pinion G is mounted on a short axle or stud F, which is carried by a differential frame or case E. The case is driven by the final drive — in this instance gears C and B. When the ring gear C turns in the direction shown, the differential case turns with it, carrying the stud F and pinion G in the same way as indicated in connection with Fig. 157. Any difference in the rotation of the rear wheel is compensated for by the rotation of the differential pinion G on the stud F while revolving bodily about the axis X–Y. If the pinion G rotates, it must roll on one of the differential gears H or H_1, and the amount of motion in rolling on the one gear is transmitted to the other as an additional turning or driving effort. Any retarded mo-

tion of one wheel results in an accelerated motion of the other. The rotation of the engine is thus transmitted to the rear wheels in proportion to the distance each wheel travels.

In Fig. 158 only one pinion is shown, and the differential case is merely a frame bolted to the main driving gear. In actual differentials, a number of pinions, usually four, are employed and usually the differential case partially encloses the differential gears. Al-

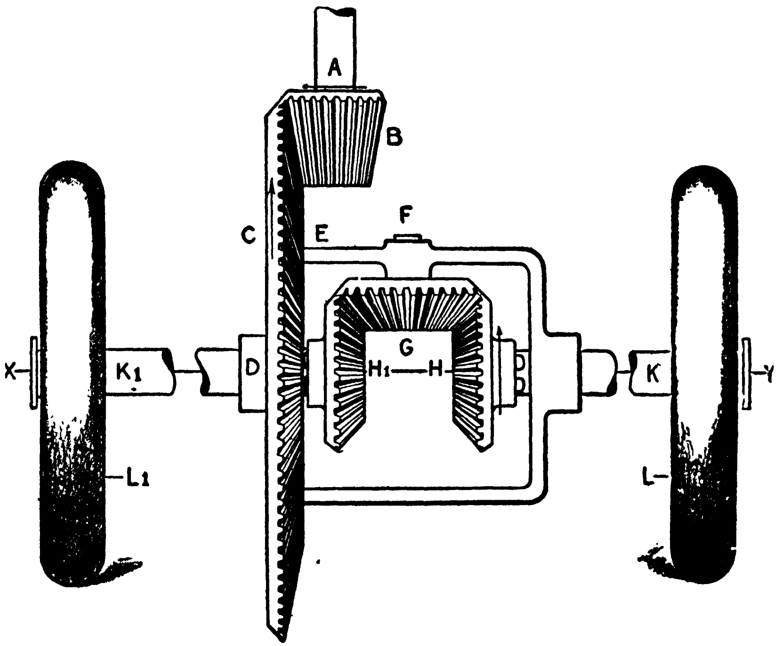


Fig. 158 — Typical bevel-gear differential and final drive

though the bevel-gear type just described is used on virtually all American passenger cars, spur-gear and worm-gear types have been used.

The objection to the bevel-gear differential is that, whichever wheel offers the less resistance is turned the faster, causing a loss of traction. If one wheel gets in the mud or loose dirt or sand, the wheel on the solid ground will not be driven while the other spins around due to the differential action. For this reason some truck differentials are provided with devices to lock out the differential to provide better traction under difficult driving conditions. In addition several designs of differential have been developed that will not permit differential action unless both wheels have traction.

Rear Axles. — From the differential, the power is transmitted

through the rear axles to the driving wheels. All rear axles on modern American passenger cars are " live " axles; that is, they include revolving shafts for driving the wheels. Were the front instead of the rear wheels driven, as in the case of a front-wheel-drive car, then the " live " axle would be at the front and the rear axle would be " dead "; that is, it would simply remain stationary.

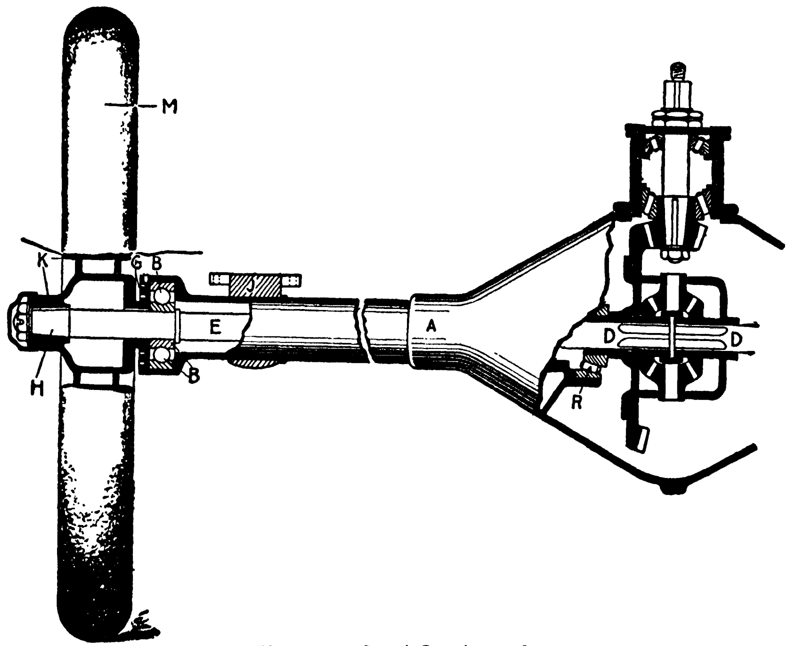


Fig. 159 — Semi-floating axle

All live axle shafts — and therefore all American car rear-axle shafts — are split into two parts, each of which is driven by one of the differential gears, usually through a spline connection. A housing completely encloses the shafts and gears, protecting them from water, dust and injury, in addition to mounting their inner bearings and providing a container for the lubricant.

There are three types of live axles: the semi-floating, the three-quarter-floating, and the full-floating. A majority of modern American passenger-car axles are of the semi-floating type.

The semi-floating axle is so called because the inner end is supported only by the differential gear, the differential case carrying the inner bearing. The inner end of the axle shaft thus is relieved of the job of supporting the weight of the car by the axle housing. Since the outer end has to support the weight of the car and take

end thrusts, this construction is called "semi-floating." Fig. 159 shows this construction. The inner end of the axle shaft *D* usually is splined to the differential gear. The hub *K* of the wheel *M* is keyed to the outer end *H* of the axle shaft. The axle housing *A* supports a bearing *B* which is placed *inside* its outer end. Both the wheel and bearing *B* must be removed in order to withdraw the axle

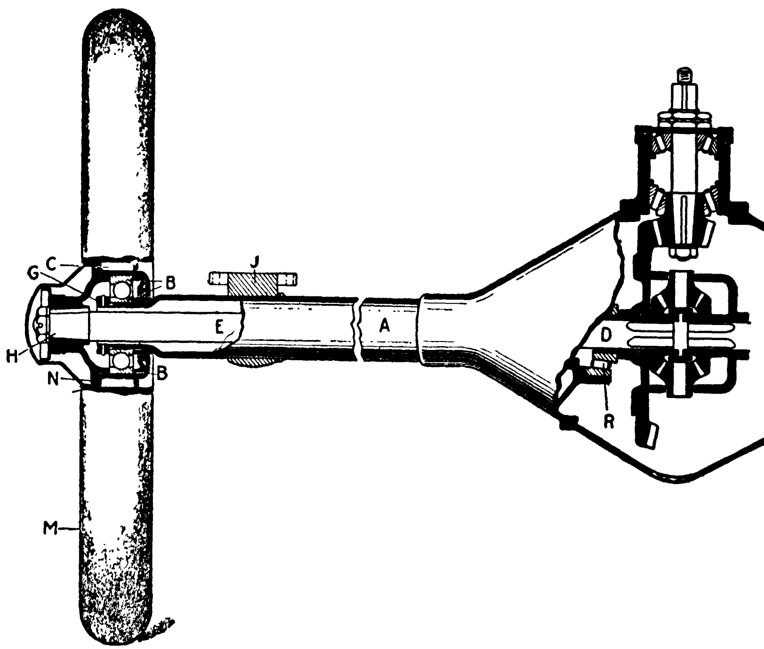


Fig. 160 — Three-quarter-floating axle

shaft. This arrangement results in the axle shaft *E* helping to support the weight of the car in addition to transmitting rotation to the wheels.

Fig. 160 shows a three-quarter-floating axle. The wheel *M* is supported by the single bearing *B* located in the center of the wheel which runs on the axle housing *A*. The axle shaft *E* is keyed rigidly to the hub *N*, thus providing the driving connection and maintaining the alignment of the wheel. The construction at the inner end of the axle shaft is the same as with the semi-floating axle. This axle is not supported by bearings at either end. As the three-quarter-floating axle has only one bearing at the outer end, it still takes some bending stresses. It, therefore, is not quite the full-floating type.

Fig. 161 shows the full-floating type. The wheel *M* is supported by two bearings *B*, running directly upon the axle housing *A*. The axle

shaft *E* is fastened to the wheel hub flange *N* by means of the coupling *K*, through which the rotary motion of the axle shaft is transmitted to the wheel. The axle shaft may be removed from the housing without disturbing the wheel by removing the hub cap and coupling *K*. The axle shaft *E* is not supported at either end by bearings, and its position is maintained by the way that it is sup-

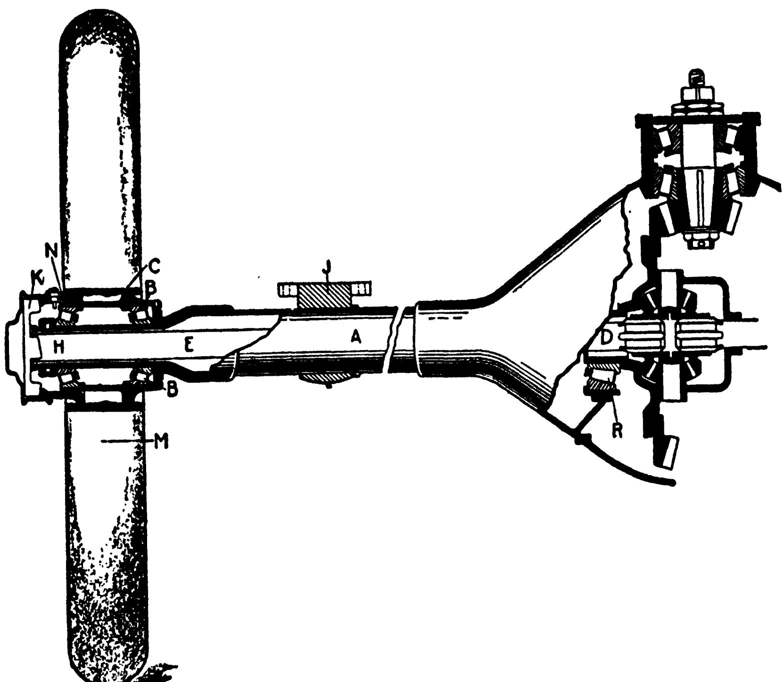


Fig. 161 — Full-floating axle

ported at both ends. Thus the axle is relieved of all strain caused by the weight of the vehicle or end thrusts; its only function is to transmit the rotary motion or torque. For this reason it is called full-floating. It is the only construction that holds the wheel in position if the axle breaks. In others, the wheel comes off and lets the car drop.

Either tapered-roller or ball bearings are used in all applications in these constructions.

Axle housings are made in a variety of materials — pressed steel, cast steel, malleable iron, cast aluminum, or steel forging. On account of its appearance a one-piece housing is called a " banjo type." Housings may also be of the split type that are bolted together, or built up from a number of pieces by welding. In addition to the

functions described previously, axle housings also must support the springs and parts of the brake assembly.

Rear-Axle Assembly Service. — Like the transmission, noise is the usual indication of trouble in the rear-axle assembly. There are, however, noises which sound as if they were coming from the rear axle, but actually they may come from the transmission or engine, or from the tires which will make a humming sound on certain types of road surface. Sometimes muffler noises may be thought to be rear-axle noises.

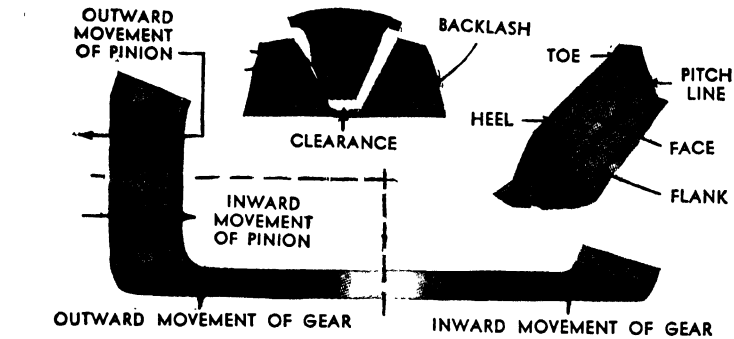
The wearing parts are either gears or bearings and, aside from an occasional broken axle, cause 99% of rear-end trouble. A grabbing clutch, too much backlash throughout the gears, or careless handling of the clutch can cause broken axles although, in modern cars, this trouble is experienced rarely. As the rear-axle pinion and ring gears become worn or out of adjustment, a humming sound will be noticed. This noise may develop into a howl under very bad conditions. The correct backlash between the teeth of these gears may be adjusted to factory specifications by using a dial gage, clamped to the differential housing.

Most cars have four directions in which to move the pinion and ring gear to make adjustments for tooth contact and backlash. The pinion may be moved backward or forward, and the ring gear and differential case assembly may be moved from side to side. These adjustments are accomplished by means of shims or adjusting screws.

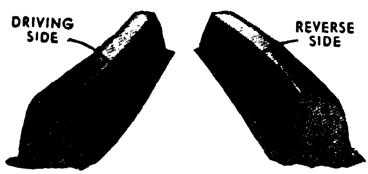
Red lead coated on both sides of several teeth at different points around the ring gear will show the pulling and coasting contact of the teeth as the engine is run in gear with the rear end jacked up. Correct tooth contact is important in order to have a quiet-running and long-lived set of gears. Correct backlash or clearance between the teeth is important for the same reason, and there is a relationship between the two, and they should be checked together.

Heel contact alone or toe contact alone (Fig. 162) will soon result in tooth breakage. Heavy flank contact and heavy face contact will be noisy. The following are adjustments that will correct these conditions:

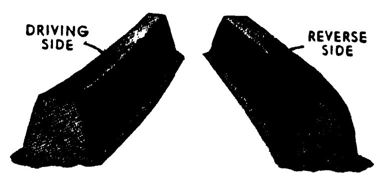
1. Heavy face contact — move the pinion in toward the ring gear.
2. Heavy flank contact — move the pinion out away from the ring gear.
3. Heavy heel contact — move the ring gear in toward the pinion.
4. Heavy toe contact — move the ring gear out away from the pinion.



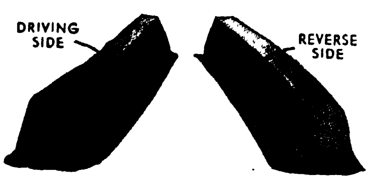
GEAR TOOTH NOMENCLATURE



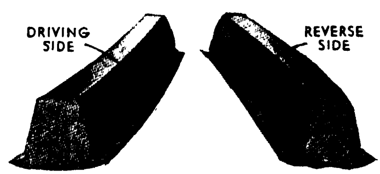
Correct tooth contact. Gears making contact as shown give best results for quiet operation and long life.



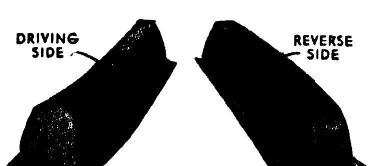
Drive bearing at heel end will cause gear to break. Move ring gear in toward pinion. Move pinion if necessary to retain proper backlash.



Drive bearing at toe end will also cause gear to break. Move ring gear out from pinion. Move pinion out if necessary to keep proper backlash.



Heavy face contact will cause noisy gears. Move pinion in toward ring gear. Move gear out away from pinion if necessary to keep proper backlash.



Heavy flank contact will result in noisy gears. Move pinion out away from ring gear. Move gear in toward pinion if necessary to keep proper backlash.

(Courtesy MoToR Factory Manual)

Fig. 162 — Gear-tooth contact of hypoid rear-axle gears

A fair rule to follow is that a drive noise (with the car being accelerated) is caused by heavy heel contact. A coast noise (clutch engaged, but no gasoline being fed when slowing down) is caused by heavy toe contact. Heavy face contact is usually the trouble when there is a noise or hum when the car is floating or being held at a steady speed.

The ends of the pinion teeth always should be flush with the inside of the ring-gear teeth after adjustments. Manufacturers' specifications will show the kind of adjustments and allowable tolerances for each differential assembly, and they should be followed closely. As soon as any rear-axle noises are heard, check for lubrication. If this is done as soon as the noise is noticed and lubrication performed, it may be that no damage has been done.

The differential pinion gears and differential side gears usually give very little trouble, and there is no adjustment for them. If there is too much play between the differential pinion gear shaft and the gears, they must be replaced. If the side gears fit loosely on the splines of the axle shaft, both the axle and gear should be replaced.

The bearings on the rear-axle assembly will give a heavy hum in an irregular tone and at times a grinding catching sound when coasting in gear when they are worn or broken. The bearings are usually removed with a special puller or in an arbor press. Bearings should be coated thoroughly with grease before re-installing.

When the rear-axle assembly is taken apart for repairs, it is necessary that all parts including the housing be washed thoroughly in gasoline, and each part examined carefully. The pinion and ring gears are always to be replaced with a factory-matched pair. Run-out (or warp) should be checked for in the ring-gear and differential casing assembly before it is put back in the rear end. The run-out should be kept within factory specifications.

Hypoid gears should be lubricated only with lubricant recommended by the manufacturer, since the gear teeth wipe across each other with great pressure when in motion, and the lubricant must be able to stand this strain. It is dangerous to add one brand of hypoid lubricant to a differential that already contains another brand, as chemical action may be set up between them to remove the lubricating qualities of both.

Axle-shaft end play must be kept within specified limits so as not to cause excessive wear on the gears, bearings, and splines. This adjustment is usually made with shims at the outer ends of the axles.

CHAPTER XXIV

RUNNING GEAR

The parts of a motor vehicle not included in the development and transmission of power may be classified generally under the heading of running gear. This classification includes such parts as frames, springs, shackles, shock absorbers, stabilizers, radius rods, wheels, rims, and tires which will be explained in this chapter. Other parts of the running gear, such as steering gear and brakes, are treated in the succeeding chapter.

Frames. — The frame is the basic structure of the motor vehicle to which all other parts are connected either directly or indirectly. On it are mounted or attached the powerplant, transmission, body, running boards, and so on. In turn, it is supported by the spring assemblies. The most important requirement of a frame is that it shall be stiff and strong enough to resist the severe twisting and bending forces to which it is subjected, particularly when the vehicle is traveling at high speed over a rough road.

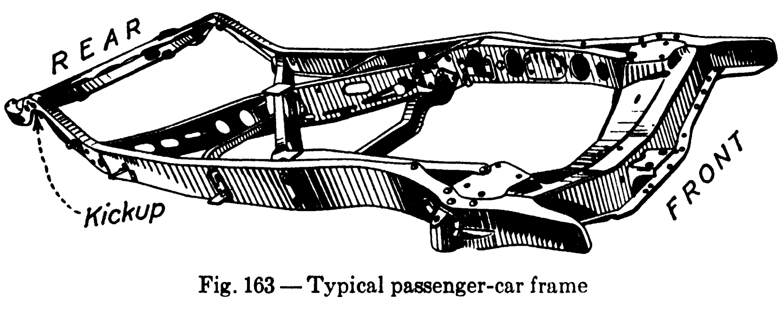


Fig. 163 — Typical passenger-car frame

As shown in Fig. 163, the typical passenger-car frame employs pressed-steel side members. These may be either of channel or box-shaped cross-section. Box-section members have unusually high twisting resistance or torsional strength. Connecting these side members are pressed-steel cross members and, on most frames, diagonal X-members. Although the X-members shown are of channel cross-section, I-beam section cross members are frequently used to give added stiffness. Joints are made by riveting or welding, some are reinforced by " gusset plates " as illustrated. The side members and X-members are built so that they are deeper at the center where

the stresses are the greatest. The frame is narrow at the front to allow for a short turning radius of the front wheels, widening out at the rear to provide ample room in the body. It will be noted that the side members are curved upward at the rear forming the "kickup." This construction is employed over the axles to lower the center of gravity of the car. The rear leaf springs connect each end of this curve (when leaf springs are used). The typical frame shown in Fig. 163 is designed for independent front-wheel suspension. Because cars with independent front-wheel suspensions have no front axles, their frames must be of heavier construction in the front than

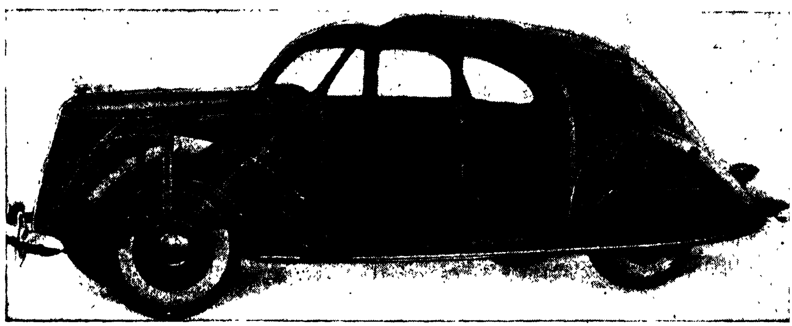


Fig. 164 — Unit frame and body construction

those that have rigid axles. Some frames for relatively light-weight cars have no diagonal X-members.

Unit Frame and Body. — This construction (Fig. 164) is used on many European and a few American passenger cars. As suggested by the name, it combines the frame and body into a single welded unit. Considerable stiffness is obtained by designing the side members on the principles of a bridge truss. The design is such in this construction that the body sheets relieve the metal framework of part of the stresses. This design results in some weight saving over the conventional separate frame and body construction.

Springs. — The automobile frame is attached to the rear axle and the front wheels or axle by springs which damp the road shock transmitted to the frame by the wheels as they travel over the road, thus protecting the units supported directly by the frame. These springs are usually of laminated leaf type or the coil type. The spring or suspension system of motor vehicles is divided into the rear-end suspension and front-end suspension, each of which will be taken up separately.

Rear-End Suspension. — Three types of rear-end suspensions are to be found on motor vehicles: (1) longitudinal leaf spring, (2)

transverse leaf spring, and (3) coil spring. Of these, the longitudinal leaf-spring type, as shown in Fig. 165, is to be found on a majority of vehicles.

Since this type of rear-end suspension generally is employed in conjunction with the Hotchkiss type of drive, as described in Chapter XXII, the leaf springs must be made strong and resilient enough to transmit the driving thrust and torque and to resist side sway, in addition to supporting the " sprung weight " of the body. Because the springs do not support the wheels, rims, tires, brakes, and rear

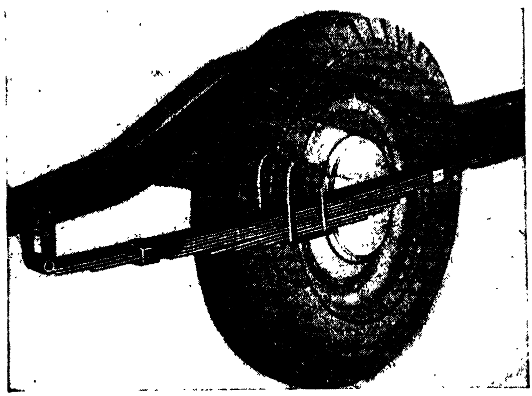


Fig. 165 — Rear-end suspension employing longitudinal leaf springs

axle, the weight of these parts is called the " unsprung weight." In order to improve the " ride " of motor vehicles, designers try to keep the unsprung weight to a minimum.

Because the shape of this leaf spring approximates a half ellipse, it is classified as " semi-elliptic " to distinguish it from one-quarter elliptic, three-quarter elliptic, and full elliptic springs. The three last types are rarely used in passenger cars. Semi-elliptic springs comprise from 6 to 14 leaves of special spring steel held together by a center bolt. The spring is clamped to the rear axle by spring clips while each end is pivoted to the frame, as shown in Fig. 165, by means of eyes formed in the ends of the longest or top leaf. One end is secured to the frame by a bolt, and the other end by a spring shackle as shown. The shackle provides a means for the spring to compensate for changes in its length, as the spring elongates in compression and shortens when it rebounds. Rebound clips are located at intermediate positions in the length of the spring, as shown. They are made tight enough to hold the leaves together when the spring re-

bounds, yet they are loose enough to permit the leaves to slide one on the other.

Usually the spring eyes through which the spring is attached to the frame are provided with bushings of some antifriction material, such as bronze or rubber.

Spring Shackles. — These swinging supports that compensate for changes in the length of the spring also may be rubber or bronze-bushed; other types are provided with ball bearings or hardened-steel

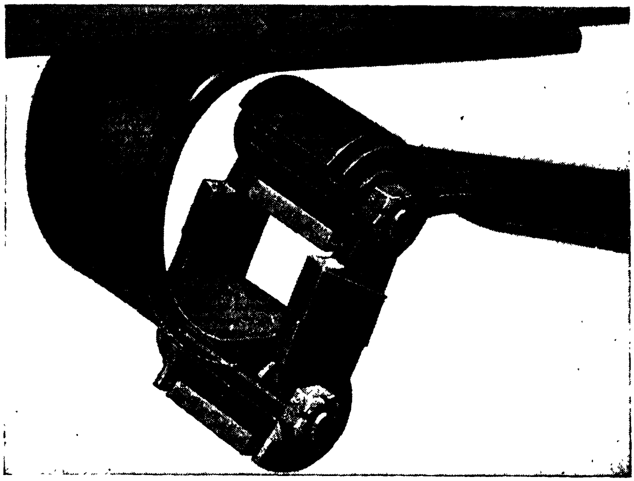


Fig. 166 — Tension-type leaf-spring shackle

bushings. The rubber bushings require no lubrication. Shackles also are classified as compression or tension types. That shown in Fig. 165 is the compression type because it is stressed under compression. Fig. 166 shows how a tension-type shackle is mounted to place it under tension.

The action of the spring leaves may be compared with a deck of cards. When held at the center and the ends are bent up, the cards slip on each other. When the pressure on the ends of the deck is released, the cards spring back to their original position. If a solid piece of cardboard of the same size as the deck were used, bending would cause it to buckle since its layers could not slip on each other. Therefore, the flexibility of a leaf spring depends upon the number of leaves composing it and, when the pressure is applied at its ends, the leaves slip on each other to conform to the changed radius of curvature. For this reason lubricant must be placed between the spring leaves. To control the characteristics of leaf springs more closely some manufacturers interpose "inserts" of various mate-

rials between the leaves at the ends of certain leaves. Rubber, fabric, and lead are common materials used for these inserts.

Weight is saved in some leaf springs by making the leaves of a special shape having parabolic edges on the under or " compression " side, instead of the conventional rectangular cross-section. This design relieves and minimizes the concentration of stresses in the leaves.

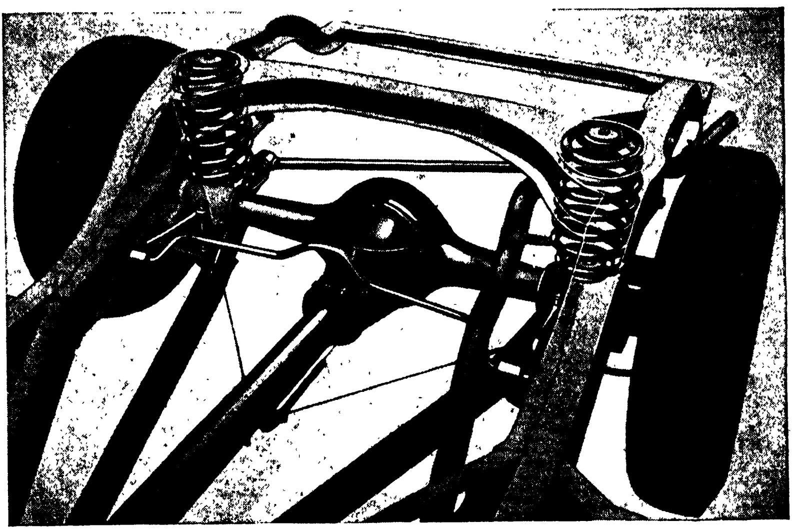


Fig. 167 — Rear-end suspension employing coil springs

Variable-Rate Springs. — Spring rate is defined as the weight necessary to depress a spring one inch. Most leaf springs have a rate that is practically constant throughout their travel. When a car goes over a severe bump or is heavily loaded, a spring having a higher rate than is required for ordinary service on smooth roads is needed to cushion the shock properly. To provide a spring with a low rate for ordinary service and a higher rate for heavy obstructions or loads, some cars are provided with " variable-rate springs." These consist of a conventional spring below which is placed a small auxiliary spring with several leaves. Because of the space between these two springs, the main conventional spring takes all the load for light loads and travel on smooth roads. But, as the upper spring is compressed under load, it is forced gradually into contact with the lower auxiliary spring. Thus, the auxiliary or helper spring strengthens the upper spring more and more as the upper spring is compressed. This arrangement provides a practically constant frequency of the

spring throughout its operating range, which is desirable for passenger comfort.

Transverse Leaf Springs. — Instead of two longitudinal springs, as just described, some passenger cars use a single transverse spring in their rear-end suspension. Such springs are mounted in "inverted" position parallel to and above the rear axle. Each end is shackled to the axle, and the frame is attached to the higher center position. Since transverse rear springs are always used in combination with torque-tube drives, they are not called upon to carry the driving thrust and torque.

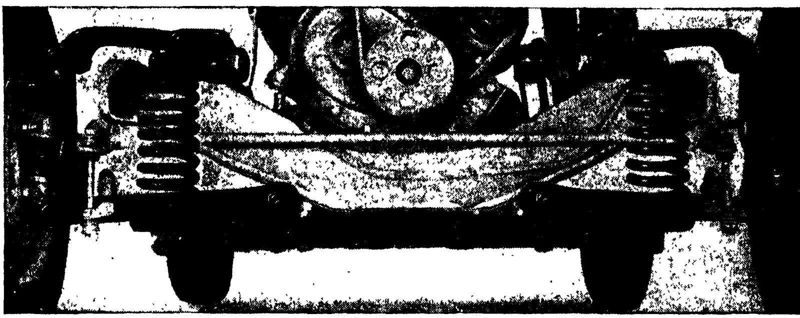


Fig. 168 — Independent front-wheel suspension using coil springs

Coil-Spring Rear-End Suspension. — Fig. 167 shows this type of suspension. The coil springs are seated in pan-shaped brackets attached to the rear axle, and are compressed against similar brackets incorporated into the frame. Like rear-end suspensions using transverse leaf springs, this suspension is always used in conjunction with torque-tube drive; therefore, the coil springs are not subjected to driving thrust or twist. In addition, stabilizers and radius rods relieve the coil springs of practically all stresses except those acting in a vertical direction. The stabilizer, shown at the front of the axle in Fig. 167, prevents excessive roll or side sway when the car is rounding curves. Stabilizers are frequently mounted in rubber bushings. The radius rod, shown at the rear of the axle in Fig. 167, keeps the rear axle and frame in lateral alignment.

Shock Absorbers. — Springs that are soft enough to absorb road shocks on compression would react violently and result in uncomfortable tossing and rolling of the car if some means were not provided to check their action. Shock absorbers are provided as part of the suspension system of motor cars for this purpose. The hydraulic type of shock absorber is used in a majority of passenger cars. They develop resistance to the spring action by forcing a fluid

through check valves and small holes. Those which offer resistance both during compression and rebound of the springs are called double-acting shock absorbers, and those which resist only on rebound are known as single-acting shock absorbers. A number of designs are available to accommodate the various types of springs and suspensions, front and rear. Frequently the rear shock-absorber housing is mounted on the frame, and the shock-absorber arm is connected to the spring, axle, or front-suspension control arm.

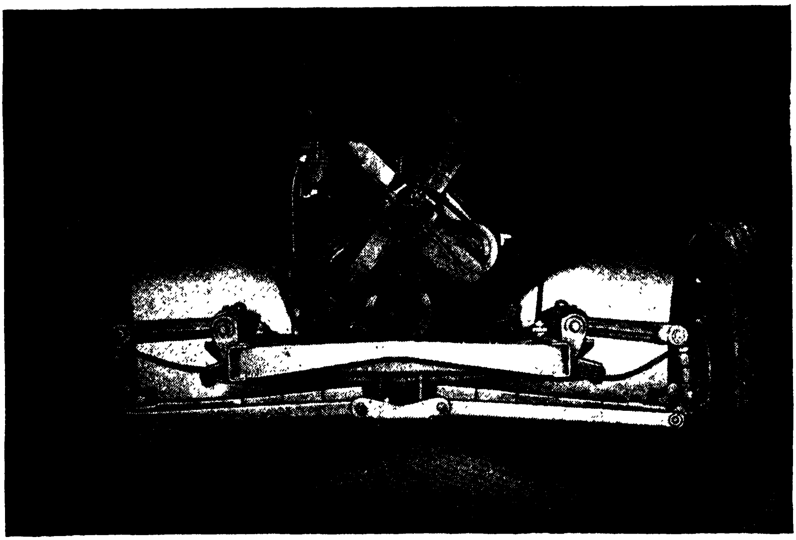


Fig. 169 — Independent front-wheel suspension using leaf spring

Front Suspension. — Passenger-car front suspensions are classified as (1) independent front-wheel suspension and (2) rigid-axle suspension.

1. Independent Front-Wheel Suspension Using Coil Springs. — This type (Fig. 168) is used on a majority of passenger cars. This design permits either front wheel to react to changes in the road-surface level without appreciably affecting the opposite wheel. Each wheel is mounted on a separate spindle which is attached to the steering knuckle. To permit the wheels to be turned by the steering gear, the spindle and steering-knuckle assembly is hinged to the vertical steering-knuckle support. The pin that forms the pivot of the hinge is usually referred to as the "king pin." The steering-knuckle support is pivoted at each end to the upper and lower control arms. The upper and lower control arms, in turn, are pivoted to the frame at their inner ends. Control arms are usually V- or

wishbone-shaped when seen from above or below. As can be seen from the illustration, the lower control arm is longer than the upper one. The arrangement of the linkage is such that the point of road contact of the tire moves up and down in a straight line during all normal movement of the control arms.

The two coil springs are supported at their lower ends in seats that are attached to the lower control arms. The upper ends of the

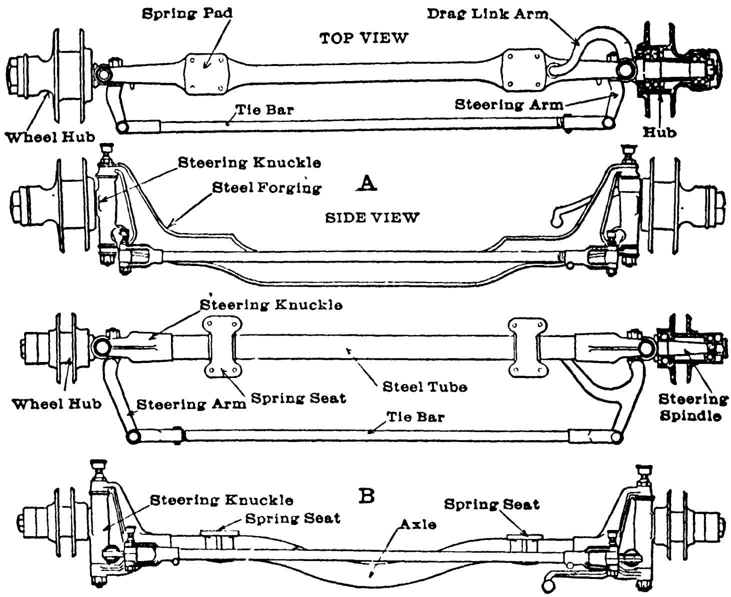


Fig. 170 — Rigid front axles

springs are compressed against seats in the frame. A shock absorber usually is employed to control the reaction of each of the coil springs. Front-end stabilizers are commonly employed to control the body roll and provide greater steering stability.

2. Independent Front-Wheel Suspension Using a Leaf Spring. — This type of suspension is similar in general construction to the coil-spring type just described except that a single transverse leaf spring replaces the lower control arms, eliminating the necessity for the coil springs, as shown in Fig. 169. This transverse spring is clamped securely to the under side of the frame at the center by means of U-bolts, and is pivoted to the steering-knuckle supports at each end as indicated in the illustration. Upper control arms link the upper end of the steering-knuckle supports to the frame as in the coil-spring type of independent front suspension. The shock-

absorber lever arms are also linked to the upper end of the steering-knuckle supports, and the shock-absorber cylinders are mounted on the frame.

3. **Rigid-Axle Front-Wheel Suspension.**—Typical rigid front axles are shown in Fig. 170. Before the introduction of independent front-wheel suspension, this type of axle was used universally in connection with leaf-type front springs. Either two longitudinal leaf springs or one transverse spring are used with rigid front axles, usually in connection with shock absorbers. These assemblies are mounted similarly to rear leaf-spring suspensions.

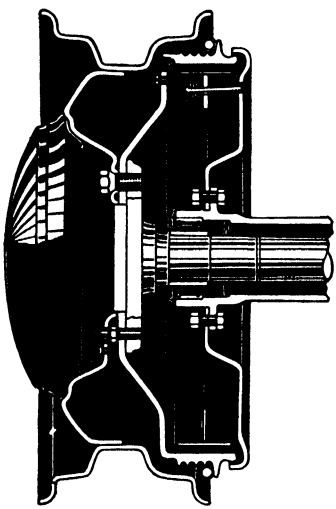


Fig. 171 — Typical steel-disc type of rear wheel

Wheel Assembly.—The wheel is generally thought of as the assembly of the hub, disc or spokes, rim, and tire. Wheels are important parts of the vehicle as they must support the weight of the car and help protect it from road shocks. In addition, the rear wheels must transmit the power, the front wheels must steer the car, and all must resist braking stresses and withstand side thrusts. Wheels must be perfectly balanced. For discussion, the assembly is divided into wheels, rims, and tires.

Wheels.—Three types of wheel are in use on passenger cars: steel disc, wire, and artillery. Of these the steel-disc type has come into the widest use. As shown in Fig. 171, it consists of a dished steel disc welded to or integral with the rim. (The rim is of drop-center type as will be explained later.) The disc is frequently dished to bring the point of ground contact under the large wheel bearing. The assembly is bolted to the brake drum, as shown, making the wheels "demountable." This means that the entire wheel assembly is easily removable by removing the lug nuts that hold the wheel in place on the brake drum, after first taking off the hub cap. The hub cap is usually held in position by spring clips attached to the disc as shown in Fig. 171. The hub cap can be pried off with a screw-driver and forced back into place. It can be seen that the brake drum acts as the true hub for mounting the wheel on the spindle or rear axle.

Wire wheels were used widely in the past, but today are found

only on a few passenger cars and on motorcycles. They are light, resilient, and easy on tires. However, they are hard to clean. The modern type consists of a pressed-steel hub and rim connected by welded spokes.

Artillery wheels use either wood or steel spokes for connecting the hub and the rim. These wheels also are demountable at the brake drums.

Rims. — Tire rims for motor vehicles have drop-center or flat-base cross-sections, as shown in Fig. 172. A " demountable rim " is one that can be removed easily from the wheel. In general, drop-center rims usually are not demountable, and flat-base rims may be demountable.

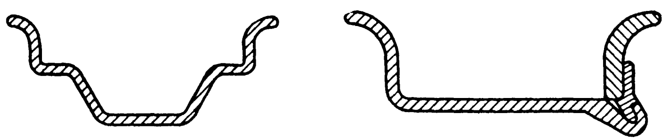


Fig. 172 — Rim types: (left) drop-center, (right) flat-base

Drop-center rims are used on virtually all passenger cars. As shown in Fig. 172, the center portion of the rim is rolled to a smaller diameter to form a well. This construction permits the removal or mounting of the tire by squeezing the beads of the tire together on one side and dropping them into the well while the opposite side is pulled over the flange.

Flat-base rims, however, require some means of mounting and dismounting tires since the bead in modern tires has little or no elasticity. In the continuous-base type (Fig. 172), one side of the rim is removable so that the tire can be installed or removed without stretching the bead. A continuous-rim side ring with a split locking ring, as illustrated, or a single side ring holds the tire in its mounted position. The continuous-base rim may be demountable or it may be an integral part of the wheel. In the demountable split-ring type of flat-base rim, the rim can be collapsed to a smaller diameter for mounting or dismounting the tire.

Tires. — Rubber tires of the solid or pneumatic type are designed to cushion the vehicle and its load from the shocks and vibration resulting from road inequalities. The springs and shock absorbers protect primarily those assemblies which are mounted above the axles. Unsprung parts and units, such as the wheels, axle assemblies, and the brake mechanism at the wheels, depend entirely upon the resiliency of the tires for protection from road shock.

Tires are classified as solid or pneumatic tires. **Solid tires** depend entirely upon elasticity of the rubber for their action. They are not used for passenger cars because they do not possess sufficient spring or cushion, and have been virtually replaced by **pneumatic tires** in trucks and buses, with the exception of certain slow-moving vehicles, such as tractors and road graders.

Pneumatic Tires. — This type employs air, confined in an inner tube, as a cushioning medium. They are more efficient than solid tires in the absorption of road shocks because the air cushion can be compressed more readily than the rubber of a solid tire can be distorted. Pneumatic tires are classified into three types according to pressure and volume: (1) high-pressure tires; (2) "balloon" tires; and (3) super-balloon or "jumbo" tires. High-pressure tires use pressures up to 120 lb per sq in.; these tires are heavier in construction and generally have more plies than the other two types. Pressures recommended for balloon tires range from 24 to 40 lb per sq in. This type is furnished as original equipment on all American passenger cars. Super-balloons operate at pressures of from 8 to 20 lb per sq in. They are available as optional equipment on passenger cars in which an extra "soft" ride is desired. Since it takes a greater volume of air in the tire to carry the same load as the pressure decreases, balloon tires are considerably larger in cross-sectional area than corresponding high-pressure tires, and super-balloon tires are considerably larger in section than equivalent balloon tires.

The cross-section of Fig. 173 shows the components of a typical passenger-car balloon tire as follows: (1) body plies, (2) tread plies, (3) cushion, (4) bead wire, (5) reinforce, (6) chafers, (7) sidewall, and (8) tread.

Body plies are composed of cotton cord fabric. In building a tire the cords are made to run at an angle of about 50 deg with a line measured straight across the tread; adjacent plies have their cords running at opposite angles. Before their incorporation in the tire, the plies either are dipped into a rubber solution or have rubber compound pressed or "frictioned" into them, after which an additional layer of rubber is added on each side. Passenger-car balloon tires have either 4 or 6 body plies. Body plies of rayon fabric are sometimes used for tires subjected to severe service because the rayon plies resist heat better than do those of cotton.

The tread plies are fabric layers which bond the tread to the cord body. They usually consist of one or two layers of openly spaced fabric. They are surrounded by heavy layers of rubber compound.

The cushion comprises a layer of rubber between tread plies and the tread itself. As the name implies, it serves as a " cushion " between these two components.

The bead is heavily reinforced with piano wire to prevent stretching and to keep the tire tight on the rim.

The reinforce is composed of strips of square-woven fabric placed around the beads to strengthen the bead area. Chafers are placed

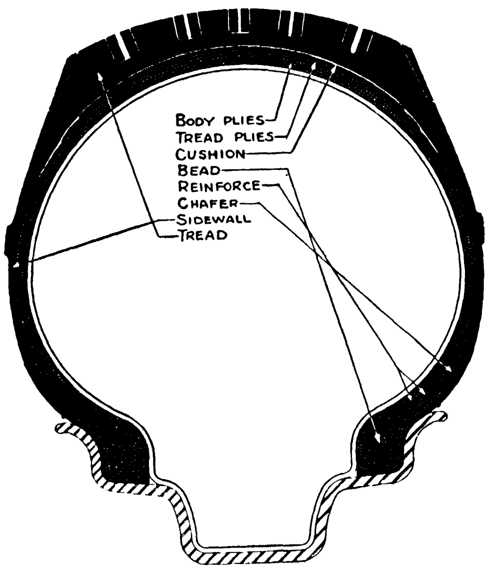


Fig. 173 — Components of passenger-car balloon tire

around the outside of the bead as shown. They serve to prevent the rim from chafing the tire. They consist of strips of rubber-coated fabric.

Sidewalls are layers of rubber compound that cover the sides of the tire. The rubber is compounded especially to provide resistance to abrasion and flexing.

The rubber tread provides abrasion resistance against the road surface and, in so doing, furnishes the traction between the road and the car necessary to operate the car. The tread pattern is designed and the rubber is compounded to minimize skidding, noise, and wear, and to give good traction characteristics. Tread wear is influenced tremendously by the type of driver and the speed of driving. A driver who accelerates rapidly, slams on his brakes, and turns corners fast will wear his tires much faster than will a more

conservative driver. Tests have shown that tread wear at 50 mph is double that at 30 mph.

Inner Tubes. — An inner tube is an endless tube of rubber fitted with a valve through which air is forced and retained under pressure. Tubes are frequently molded to conform to the shape of the tire. Special types of tubes are available which minimize the danger of punctures or blowouts. These tubes employ self-sealing constructions or inner and outer tubes.

Tire Chains. — Chains are used to gain traction in snow, rough ice, or muddy road conditions. Many types are available. Where possible they should be installed before the need for their use actually exists. Also they should be removed as soon as possible after they are no longer needed since they wear out rapidly, damage tires, and put an extra strain on the engine and power-transmission system.

Importance of Maintaining Tire Pressure. — Since a tire is designed to operate at a certain pressure when installed on a car of known weight and characteristics, it is of utmost importance that this pressure be maintained to obtain maximum service from the tire. Under-inflation causes severe flexing of the tire plies, sidewalls and other components; excessive heat; and premature failure. It is the cause of a majority of tire failures. Over-inflation, on the other hand, overloads the components of the tire and causes excessive tread wear and hard riding.

Servicing the Running Gear

Frames. — Bent or sprung frames may be straightened accurately by using special equipment and hydraulic jacks made for the purpose. All car manufacturers give detailed information as to frame measurements. To do a good job of frame straightening, these specifications should be followed for alignment. The eye is not an accurate guide. Cracked or broken cross or side members, of course, should be replaced.

Springs and Shackles. — Leaf and coil springs may sag after long service. Such sagging springs will affect the alignment of the front end, in addition to providing a poor ride. They should be replaced when in this condition. Coil springs require no other service attention.

Leaf springs must be lubricated periodically by forcing between the leaves a good spring oil or graphite (as recommended by the car manufacturer). Metal spring covers, such as are standard equipment on some cars, retain the lubricant for long periods.

Rebound clips must be kept tight since they help to keep the leaves from breaking as the car body goes up or rebounds after hitting a bump.

Dry leaves, inoperative shock absorbers, and overloading also will break springs. A spring with a broken or cracked leaf should be replaced with a new one in order to protect the car and body against strain.

Spring shackles should be removed and replaced with new shackles and bushings when worn out. Wear is indicated by play between the shackle and bolt. For replacing these parts, it is advisable to refer to the shop manual, as there are a number of types of shackles and bushings. All bushings except the rubber type should be lubricated at regular intervals. If not of the type in which grease is forced in through a nipple, it is necessary to remove the shackles and clean them thoroughly in gasoline, to remove old grease and rust.

Shock Absorbers. — Direct-acting or " telescopic " type shock absorbers must be removed from the car and filled with shock-absorber fluid at regular intervals as recommended by the manufacturer, or when necessitated by their condition. The dirt should be cleaned away from around the filler plug before removing the plug. When filling the shock absorber with the fluid specified by the car manufacturer, a little air space should be left for expansion of the fluid. The plug should then be replaced and the car jounced as a test. If the shock absorber does not seem to work properly, the shock-absorber arm should be disconnected and worked up and down by hand. There should be a steady resistance in both directions if the shock absorber is a double-acting type. If there is free play, air may be trapped in the passages. In such a case more fluid should be added and the arm worked up and down until all the air pockets are gone, as indicated by steady resistance.

To locate a leak in a shock absorber, it first should be filled with fluid and cleaned thoroughly. Then it should be run over a rough road, noting afterward any fluid that has leaked out on the cleaned housing of the shock absorber.

If an operating valve inside the shock absorber is stuck open, the arm will move easily when the absorber is being tested. If one of the valves is plugged shut, the arm will move much too hard. In either case, the shock absorber must be removed and taken apart for repair.

The direct double-acting type of shock absorber also must be taken off the car to be refilled. Those not provided with filler plugs must be taken apart to fill. This job should not be attempted with-

out following factory specifications closely and using the special tools recommended.

Often noise results from loose shock-absorber arm-to-frame connections. These joints should always be kept tight.

Because of the close relationship of the front suspension to the steering gear, the service of these two systems will be discussed together at the end of the following chapter.

CHAPTER XXV

FRONT-END ALIGNMENT, STEERING SYSTEMS, AND BRAKES

Camber, Toe-In, Caster, and King-Pin Inclination. — Front wheels usually are not mounted parallel with each other as might be supposed but, in most cases, deviate slightly to improve steering and operation. For example, the front wheels are often tilted outward at the top and inward at the bottom as shown in Fig. 174.

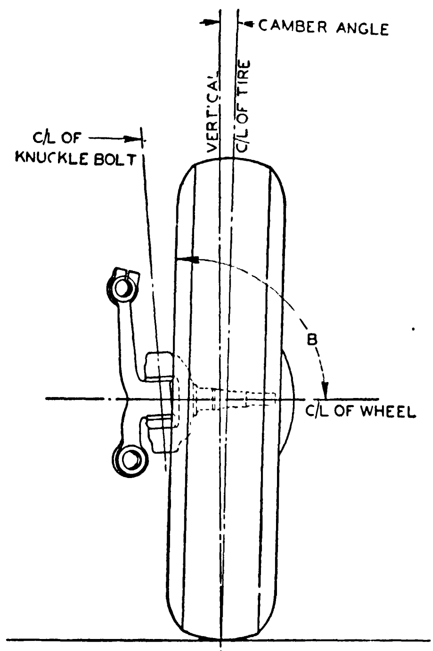


Fig. 174 — Camber and king-pin angles

This is called "camber." The front wheels also are usually drawn together slightly in front. This is called "toe-in." "Caster" is the backward tilt of the king pin at the top, as illustrated in Fig. 175. Caster tends to make the wheels align themselves with the direction in which the car is moving. The principle is the same as that employed in furniture casters.

"King-pin inclination" is the inward tilt of the king pins at the

top. This design is used to reduce steering effort. In theory, the king pin is inclined so that a line through the center of the king pin extended downward intersects with the tire at its point of contact with the road.

Steering System. — The function of the steering system is to convert the rotary movement of the steering wheel in the driver's hands into angular turn of the front wheels which pivot on hinges formed by the steering knuckles, steering-knuckle supports, and the king pins. As explained in the previous chapter, the front wheels are carried on the spindles of the knuckles and run in tapered-roller or ball bearings. The steering system also must operate easily and must absorb a large part of the road shocks, thus preventing them from being transmitted to the driver.

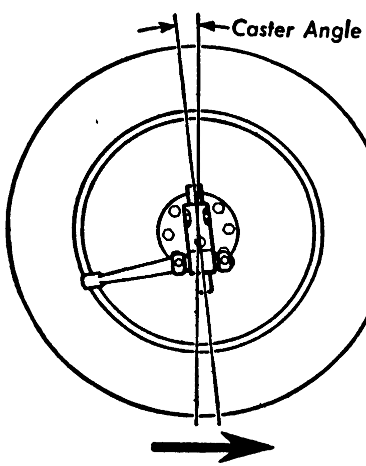


Fig. 175 — Caster angle

Fig. 176 shows a typical steering system assembly. When the driver turns the steering wheel in this system, the resulting motion is transmitted down a steering tube (which revolves inside the steering column) to a worm gear at the end of the steering tube. (See Fig. 177.) A two-toothed roller is meshed with the threads of the worm gear so that, as the steering wheel is turned, this roller moves in an arc around the roller shaft. The roller is mounted on ball bearings as shown, or on some other type of antifriction bearing. The angle of the worm threads is made a little flatter at the center to give more accurate steering control when the wheels are in the straight-ahead range where most of the driving is done. This swinging motion of the roller is transmitted to the wheels through the pitman arm (which is keyed to the roller shaft), the drag link, the intermediate steering arm (which pivots in a frame bracket), the two tie rods, and the two steering arms, as shown in Fig. 176. This type of steering linkage is called " center " steering linkage, and the steering gear is the " worm-and-roller " type.

When a turn is made, the following operations will take place: The steering gear and the worm gear are turned to the right or clockwise. The roller is forced upward causing the pitman arm to push

forward on the intermediate steering arm, thus turning the wheels to the right.

Types of Steering Gear. — The worm-and-roller steering gear just described (Fig. 177) is widely used on American passenger cars. Three other types, however, are in use, all of which employ the same principle of transmitting the motion from the steering tube to the

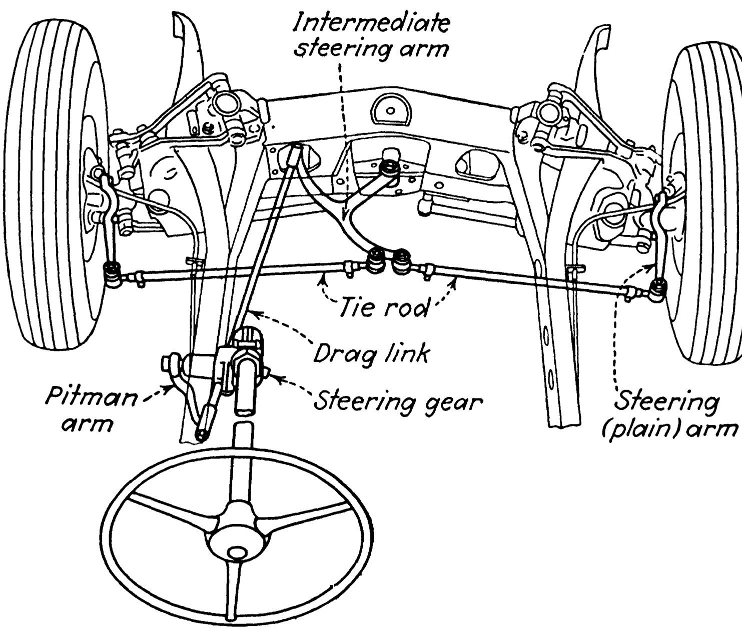


Fig. 176 — Steering system with center linkage and worm-and-roller steering gear

pitman arm: the " worm-and-sector " type, the " cam-and-double-lever " type, and the " worm and ball-bearing nut " type. Except that a gear sector is used instead of the roller shown in Fig. 177, the worm-and-sector type (Fig. 178) is virtually of the same construction as the worm-and-roller type. In the cam-and-double-lever steering gear (Fig. 179) a cam replaces the worm used in the two types just described. The cam is cylindrical in shape, its actuating part being a groove of variable pitch made narrower at the center than at the end. This design provides " non-reversibility " in the center part of the cam where most of the car steering takes place. This feature will be explained later in this chapter. The twin levers are mounted on a cross shaft and are located so that they engage the cam from the side, as contrasted with the underneath position of

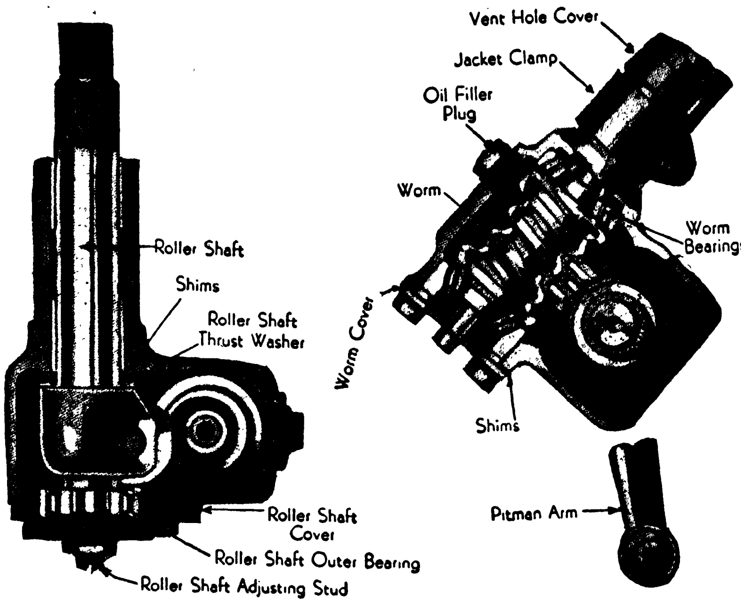


Fig. 177 — Worm-and-roller steering gear

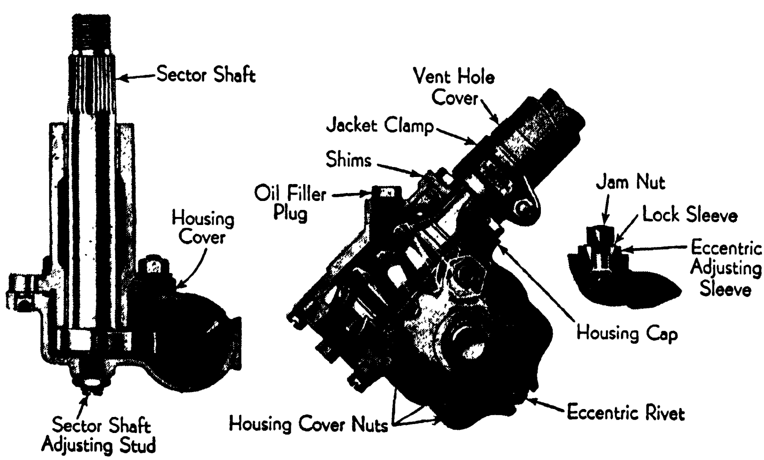


Fig. 178 — Worm-and-sector steering gear

the sector or roller in the worm types. It is obvious that the worm-and-roller type has lower frictional losses than have the latter two types.

The worm-and-ball-bearing nut type is shown in Fig. 180. The nut is " threaded " to the worm by a train of ball bearings. When

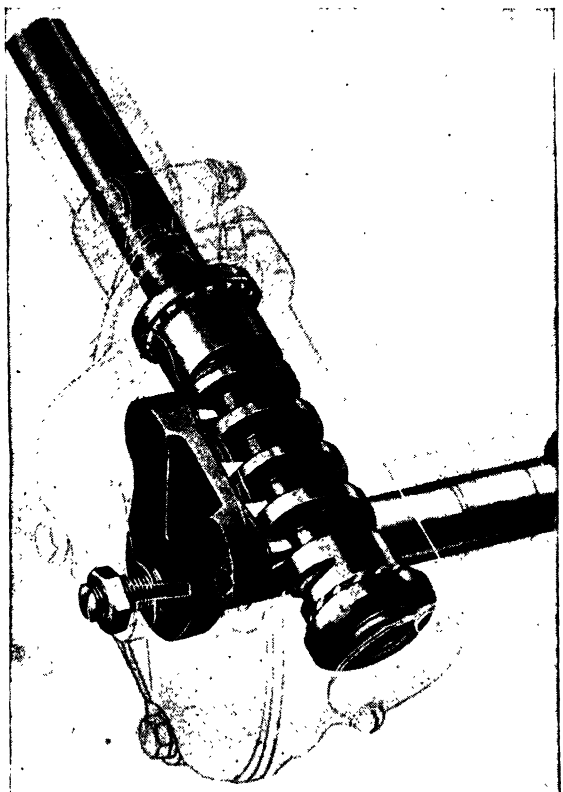


Fig. 179 — Cam-and-double-lever steering gear

the steering gear is turned, the balls which reach the top or bottom of the nut, as the case may be, pass through a return tube to the other end of the unit, thus providing a continuous supply. This design also minimizes friction.

Types of Steering Linkage. — Various types of steering linkage other than the center steering linkage just described are used in passenger cars.

The so-called " conventional " type (Fig. 181) is commonly used in cars provided with rigid front axles. In this linkage the pitman

arm is connected directly by a connecting rod known as a "drag link" to an arm attached to the left-hand steering knuckle, and the motion is carried across from this arm to an arm on the right-hand steering knuckle by means of a tie rod.

Other types used with independent front-wheel suspension are the "cross," "relay," and "fore-and-aft" linkages.

Fig. 182 shows the direct cross type in which the steering-gear pitman arm is connected directly to one tie rod which, in turn, is con-

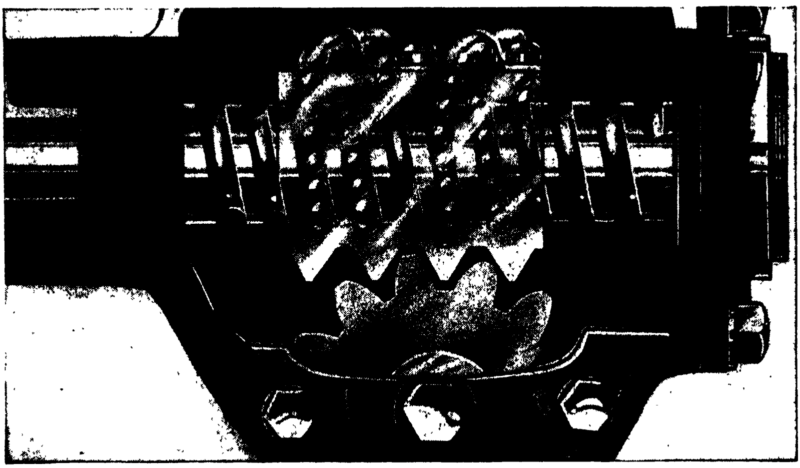


Fig. 180 — Worm-and-ball-bearing-nut steering gear

nected to another. The outer ends of these tie rods are connected to the steering arms.

In the "relay" type shown in Fig. 183, one end of a transverse steering relay rod is connected to the pitman arm and the other end is connected to an idler arm. Tie rods connect the relay arm to the steering arms so that the side-to-side motion imparted to the relay rod by the pitman arm turns the wheels as desired.

The principal distinguishing feature of the "fore-and-aft" linkage is that the drag link and pitman arm are mounted on the left side of the frame so that they are moved "fore and aft" as the steering wheel is turned.

Reversibility of Steering Gear. — A steering gear is defined as reversible when it transfers road shock back through the steering wheel to the driver. Since reversibility is obviously an undesirable feature, passenger-car steering gears are made as nearly non-reversible as is commensurate with the maintenance of other necessary operating characteristics.

This is accomplished chiefly by the design of the worm or cam, and its meshing roller, lever, nut, or segment of the steering gear. When a worm gear is employed, it is generally considered non-reversible when the thread makes an angle of less than 6 deg with

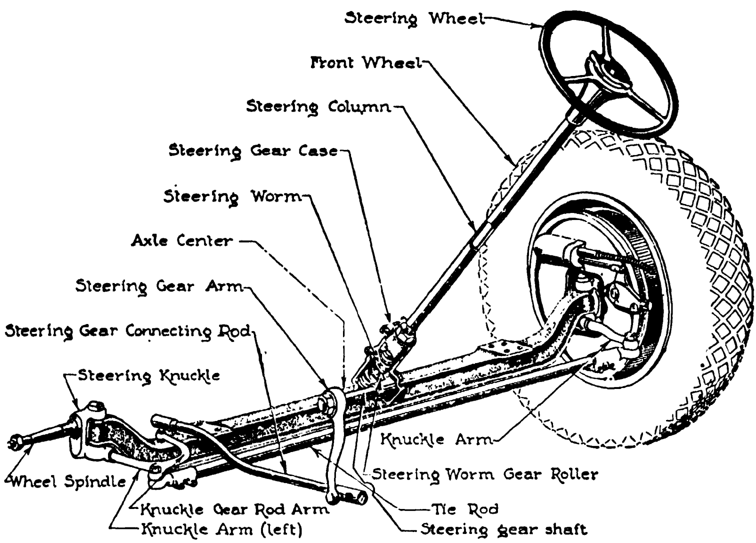


Fig. 181 — Steering linkage commonly used with rigid front axle

a line perpendicular to the axis of the worm. Angles slightly greater than this are thought of as semi-reversible. Because a strictly non-reversible steering gear would not tend to straighten out after negotiating a turn, and would not easily follow the course of a rutted road without undue stress on the mechanism, the intermediate or

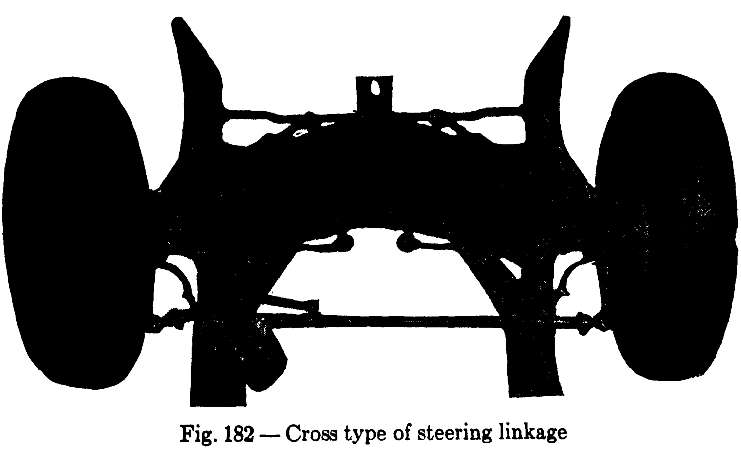


Fig. 182 — Cross type of steering linkage

semi-reversible type of steering gears are used on most passenger cars.

Steering Ratio. — The term steering or reduction ratio, as applied to a steering gear, refers to the number of turns on the steering wheel required to produce one turn of the steering-gear shaft to which the pitman arm is attached This ratio varies between 14:1 and 24:1 in passenger cars; it is generally low for small, light cars and increases as the cars grow larger. By varying the pitch of the worm or cam so that it is flatter at the center, many steering gears have a variable reduction ratio which is higher for the straight-ahead range and lower for the outer ranges.

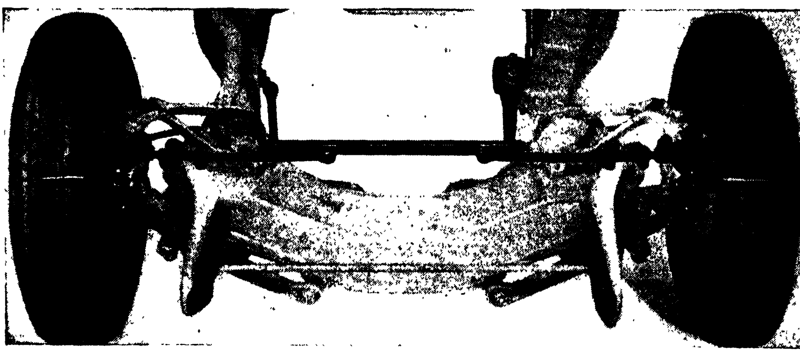


Fig. 183 — Relay type of steering linkage

Turning Radius. — The radius of the circle on which the outside front wheel moves when the front wheels are turned to their extreme outer position is known as turning radius. This radius varies from 15 to over 23 ft for passenger cars, and may be as high as 45 ft for buses or trucks. Since the maximum rotation of the steering knuckles is seldom more than 35 deg from straight-ahead position, turning radius is usually proportional to the wheelbase of the car.

Steering Geometry. — In order to avoid tire slippage when a motor vehicle makes a turn, each wheel must roll on an arc which has a common center with the arcs of the other wheels of the vehicle, as shown in Fig. 184. With the arrangement used on horse-drawn vehicles involving a front axle pivoted in the center as shown at the left in Fig. 184, it is apparent that this requirement is satisfied easily. Because of difficulties of construction, this design is not practicable for motor cars. To meet this requirement in the construction used in motor vehicles, in which each front wheel moves about its own pivot (the king pin), it is necessary to have the inside wheel turn through a larger angle than does the outside wheel, as shown in Fig. 184 at

the right. This arrangement makes the two front wheels toe out slightly when making a turn.

As a result, all steering linkages used in passenger cars are designed always to turn the inside wheel through a larger angle than the outside wheel when making a turn. Since these linkages cannot be made to maintain angular values that are absolutely correct for all turning angles, they are designed to give theoretically correct turning angles for the small turning angles in the straight-ahead range where the most driving is done and where speeds are generally higher.

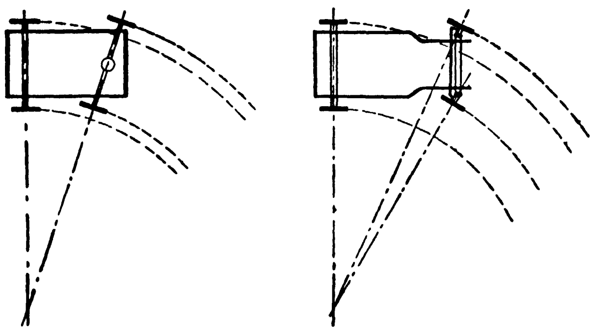


Fig. 184 — Steering geometry of the horse-drawn vehicle (left) and the motor vehicle (right)

Brakes. — The use of brakes on motor vehicles serves two purposes: (1) To aid in controlling the speed of the vehicle and to stop it when and where desired; (2) to hold the vehicle in place without the presence of the operator after it actually has been brought to a complete stop.

To accomplish these purposes most motor vehicles have two independent brake systems — a service brake operated by a foot pedal and a parking or emergency brake operated by a hand lever.

Brake Requirements. — Brakes act to convert the kinetic or speed energy of the car to heat energy by means of the brake contact surfaces. The braking power must be proportional to the weight and speed of the vehicle. This power depends upon the coefficient of friction between the frictional brake members, the pressure that forces them together, the total area of the contact surfaces, and the resistance of the tires to sliding or rolling on the road. The total braking area on American passenger cars varies between 53 and 263 sq in., depending to a large extent upon the size and weight of the vehicles. The pressure exerted on the brakes is directly proportional to the pressure exerted at the foot pedal or manual lever. In hydraulic

service brakes, the pressure exerted at the foot pedal is multiplied approximately five times at the hydraulic wheel cylinders.

Since, when the brakes are applied on a four-wheel braking system, there is a transfer of weight from the rear wheels to the front wheels, the system must be designed so that only a safe proportion of braking effort takes place on the front wheels. Otherwise, the front brakes may lock and interfere with steering.

Brakes operate most efficiently when they are applied so that the wheels do not quite lock but continue to turn without slipping on the road. This is because more energy can be absorbed when the wheels are turning than when the brakes lock the wheels so that the tires slide on the road. In other words, the power absorbed by the friction of the brake drums and lining, the frictional losses of the power-transmission system, and the rolling friction of the tires, is greater than the sliding friction of the tires on the road. For this reason it is usually safer, especially when traveling on slippery highways, to use the deceleration of the engine, with or without brakes, rather than the brakes alone for slowing down a car. In addition, locked brakes cause excessive tire wear.

Classification. — Brakes are classified according to the method of applying the stationary brake bands or brake shoes to the revolving brake drums as internal-expanding or external-contracting. They also are classified as mechanical or hydraulic according to whether the braking force is transferred from the foot pedal or hand lever to the brake shoes by means of mechanical linkage or by hydraulic pressure. Wheel brakes also are distinguished by the number of wheels on a vehicle to which they are applied, as two-wheel brakes and four-wheel brakes.

Hydraulic Brakes. — The internal-expanding four-wheel hydraulic brake system has virtually replaced all other types for passenger-car service brakes. A typical braking system which combines four-wheel hydraulic service brakes with a two-wheel mechanical parking and emergency brake operated by a hand lever, is shown in Fig. 185.

The hydraulic braking system consists essentially of a master cylinder and plunger which is connected by tubing (usually copper) to hydraulic cylinders at each of the four wheels. The pistons of these cylinders move out to apply the pressure to the wheel brakes. The system is filled with liquid under light pressure when the brakes are not in operation. This liquid is usually a mixture of glycerine and alcohol or castor oil and denatured alcohol. Each wheel brake comprises a cylindrical brake drum which is mounted on the inner

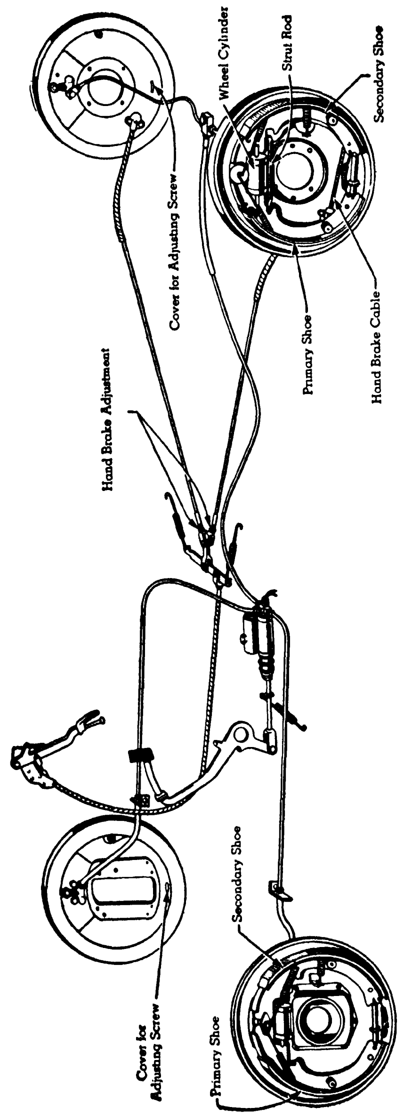


Fig. 185 — Passenger-car braking system comprising four-wheel hydraulic service brakes and rear-wheel mechanical parking brakes

side of the wheel and revolves with it, and two brake shoes which are mounted inside the brake drums and do not rotate. The shoes are fitted with a heat and wear-resisting brake lining on their outer surfaces. These non-rotating shoes are forced out against the inner surface of the revolving brake drum to slow down or stop its motion by the action of the hydraulic cylinders when the brakes are applied.

The service brake pedal is linked to the master cylinder so that, when the driver depresses the pedal, the master-cylinder piston is forced into the cylinder, thus compressing the fluid in the cylinder and placing the entire hydraulic system under considerable pressure. This pressure is conducted instantaneously to the wheel cylinders on each of the four wheel brakes. The fluid pressure in the wheel cylinders forces their pistons outward. These pistons, in turn, force the brake shoes out against the brake drums. When the driver releases the brake pedal, the pressure in the hydraulic system immediately drops to its original low value. This pressure drop permits a return spring in the master piston to return this piston and the brake pedal to their original positions, and allows retracting springs on the wheel brakes and return springs in the cylinders to pull the brake shoes out of contact with the brake drums into their original positions. At the same time these retracting springs on the wheel brakes help the cylinder return springs to force the wheel pistons back to their original inward positions. This movement of the wheel pistons returns fluid to the master cylinder. The master cylinder is kept filled with liquid by a reservoir.

An outstanding advantage of such hydraulic brake systems is that equal pressure is transmitted to the four brake cylinders at the same instant. They also are usually more powerful than corresponding mechanical brake systems.

Important parts of the hydraulic brake system will now be considered in more detail.

Hydraulic Wheel Brakes. — The hydraulic internal-expanding wheel brake provided on each of the four wheels of the braking system shown in Fig. 185, is detailed in Fig. 186. The brake shoes are secured to stationary backing plates which, on rear wheels, are attached to the axle housing and, on front wheels, to the steering knuckle. Brake drums are thin cylindrical members, the outside ends of which are closed and the inside open to admit the brake shoes. In passenger cars, brake drums are made of cast iron, cast iron and steel, steel, chrome-nickel iron, composite, and "centrifuse" construction. The last construction consists of a cast-iron liner plus a steel back. In this design the steel supplies the strength and the

cast-iron inner surface has a higher coefficient of friction and dissipates heat more rapidly. Passenger-car brake drums are between 8 and 15 in. in diameter.

Wheel brakes usually contain two shoes — a primary shoe on the left and a secondary shoe on the right — as shown in Figs. 185 and 186, although some have three shoes. These shoes are semi-circular

Fig. 186 — Hydraulic wheel brake with double-acting piston and single anchor pin

segments of steel with a lining of specially treated asbestos (or other heat and wear-resisting friction material) riveted to the outside or bearing surface. Some brake shoes have molded brake lining on both shoes, and others have woven brake lining on the primary shoe and molded brake lining on the secondary shoe. Passenger-car brake linings are from $1\frac{1}{8}$ to $2\frac{1}{2}$ in. wide and from 5/32 to 13/32 in. thick.

In the wheel brake shown in Fig. 186, a double-acting hydraulic cylinder and pistons force the two shoes into contact with the inner surface of the brake drum when the brakes are applied, thus slowing up or bringing to rest the rotation of the drum and wheel. Front wheel brake pistons of larger diameter than those on the rear are

provided on many cars to take advantage of the greater braking ability of the front wheels, due to the weight shift to the front wheels during braking. The two shoes are linked together at the bottom and are attached to the stationary backing plate by the single anchor pin shown at the top. The joint between the brake shoes and anchor pin is of the sliding type designed to permit a slight sidewise movement of the brake shoes.

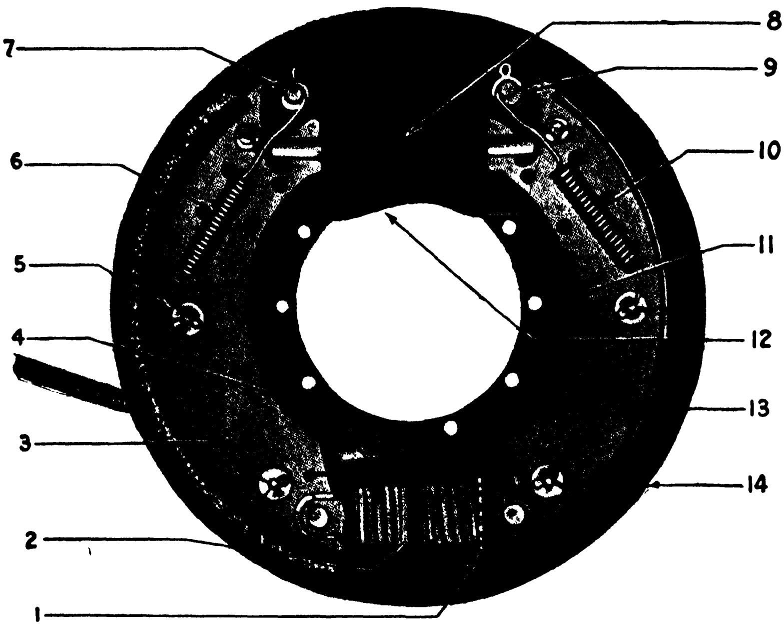


Fig. 187 — Hydraulic wheel brake with double-acting piston and two anchor pins

All modern hydraulic wheel brakes have a " self-energizing " or " servo " feature in which the force of the rotating drum is utilized to increase the brake pressure. In Fig. 186, for example, when the vehicle is traveling forward, the drum is rotating in a counter-clockwise direction. When the brakes are applied, the primary shoe at the left, because of the friction of the rotating drum, tends to move in the direction of the drum's rotation. Since the primary shoe is linked to the secondary shoe at the bottom as shown in Fig. 186, the secondary shoe is forced around against the anchor pin at the top. The result of this wrapping action is that both shoes are forced into tighter contact with the drum and the braking pressure is more uniformly applied. When the brakes are applied while the car is in

reverse, the secondary shoe tends to move in a clockwise direction against the primary shoe, forcing the latter against the anchor pin.

In the two-anchor type of wheel brake shown in Fig. 187, the left-hand or primary shoe tends to pivot about its lower anchor pin when the brakes are applied with the car in forward motion, thus forcing the primary shoe more firmly against the drum. When the brakes are applied while the car is in reverse, the right-hand or secondary brake shoe tends to pivot about its anchor pin because of the friction of

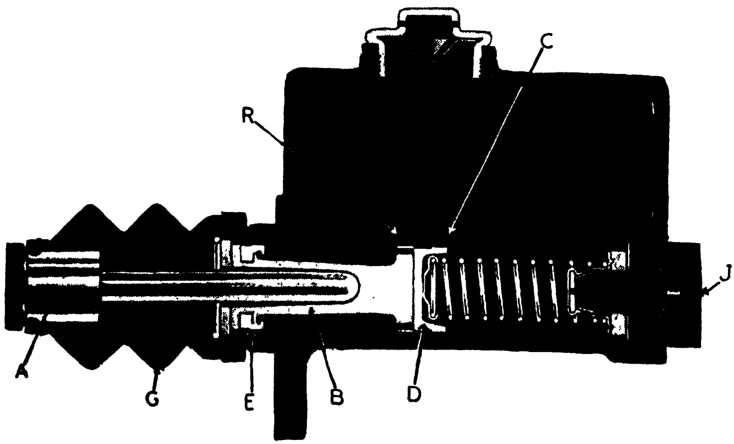


Fig. 188 — Hydraulic-brake master cylinder

the clockwise-moving brake drum, forcing it more firmly against the drum.

The action of the brake-shoe retracting springs and piston-return springs was explained earlier in this chapter. The adjusting screw shown at the bottom in Fig. 186 is used to adjust the brake shoes for lining wear.

In addition to the single-cylinder type of wheel brake with two opposed pistons are other types which have a single cylinder with one piston acting on one shoe, or two single-acting pistons, one at the top and one at the bottom, each acting on a different shoe.

Hydraulic-Brake Master Cylinder. — Details of a typical hydraulic-brake master cylinder are shown in Fig. 188. A " compensating port," *C*, can be seen in the upper wall of the cylinder. This port opens directly to the reservoir. When the foot pedal is in the " off " position, liquid may flow from the reservoir through the relief port into the master cylinder, supply lines, and wheel cylinders to make up for any fluid that may be lost or to compensate for shrinkage cooling of the liquid. In addition, when the liquid expands because

of heat, the excess passes back into the reservoir, thus preventing an undesirable pressure rise in the system. When the brake pedal is depressed and the master-cylinder piston moves forward to force liquid under pressure into the system, the compensating port is sealed out of the system. The piston is constructed so that reserve fluid from the reservoir passes through the filler port, *R* in Fig. 188, in a recessed area, supplying fluid on both sides of the piston. The reservoir is kept at least half full of fluid to compensate for fluid

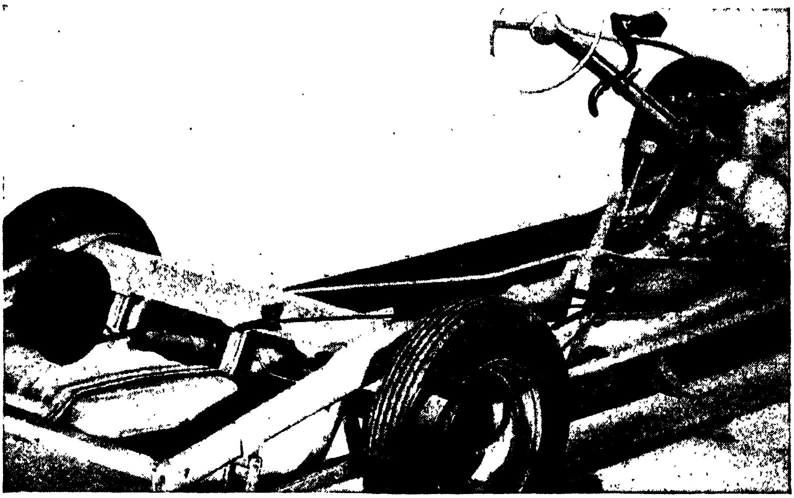


Fig. 189 — One linkage arrangement for mechanical parking or emergency brake

expansion and contraction due to temperature changes. When the brake pedal is depressed, the increased pressure closes the stop-light switch, thus lighting the rear stop lights.

Parking and Emergency Brake. — Mechanical brakes operated by a hand lever are generally used for the parking and emergency brake in passenger cars. These brakes usually act on the rear wheels (Fig. 185) but, in some cars, they are attached to the transmission or the propeller shaft. As shown in Fig. 185, the hand-brake lever usually is mounted in the driver's compartment under the instrument panel at the left. When the brake is pulled on, the lever is locked in place by a ratchet. It is released by squeezing the lever and control finger together. In one typical construction a pull rod runs from the hand-brake lever to an idler lever mounted on a frame cross member as shown in Fig. 189. When the hand brake is pulled toward the driver, the idler lever is pulled forward against the action of the pull-back spring, pulling with it the two cables which engage the rear wheel brakes. The pull on the cables operates cams, toggles,

double levers, "strut rods," or other mechanical devices for pushing the brake shoes apart and into contact with the brake drums in the same manner as do the pistons in the hydraulic service brakes. The brake shoes and drums are the same as those used for the rear wheels in the hydraulic service-brake system.

The parking and emergency brake also may be located to act on the rear of the transmission or the forward end of the propeller shaft. These brakes may be either of the external-contracting drum type or a disc type. The disc type comprises a special steel disc with air-cooling passages between its faces. Operation of the hand lever forces the brake shoes against the faces of the disc. Brakes on the propeller shaft are fast disappearing from American passenger cars.

Mechanical Four-Wheel Service Brakes. — These wheel brakes are of the internal-expanding type and are much the same as the hydraulic wheel brakes except that a mechanically actuated cam or other separating device replaces the hydraulic pistons for forcing the brake shoes out against the drums. The physical force applied to the foot pedal by the driver is transmitted to the cams by a linkage of rods, cables, cross shafts, and springs. Various methods are used to equalize the pull transmitted to the four wheel brakes.

In some systems the rear wheel brakes have double sets of drums and shoes so that the mechanical service brakes, and mechanical parking and emergency brakes can operate independently. The service-brake drum usually is larger than the parking-brake drum.

Power Units or Boosters. — These units are provided on some of the larger passenger cars and buses which require considerable braking power. They contribute about two-thirds of the braking effort, the remainder being furnished by the driver's foot pressure. The vacuum type utilizes the power from the vacuum created in the intake manifold. When the brake pedal is depressed, a valve opens in the system, creating a suction in an operating cylinder which actuates a piston connected to the brake linkage. These vacuum power units or brake boosters can be installed on a vehicle without disturbing the original brake system.

Air Brakes. — Since heavy buses and trucks require a heavier braking effort than can be furnished by the driver's foot pressure, compressed-air powered brakes are used widely for these heavy vehicles. Instead of foot pressure, in one design, these brakes are set by the pressure of compressed air acting against flexible diaphragms in brake chambers. These diaphragms are connected to the brake rods and controlled through a hand- or foot-operated valve. The brake rods connect to brake-operating cams on the wheel brakes similar to those of the mechanical service-brake system just de-

scribed. The brake valve controls brake operation by directing the flow of air from a reservoir against the diaphragms in the brake chambers during brake application, and from the brake chambers to the atmosphere during release. An air compressor furnishes compressed air to the reservoir whenever the air pressure in the reservoir falls below a set value.

"Hill-Holders." — These units are auxiliary braking devices for use on hydraulic systems. The units automatically prevent the car from backing down on a grade (after it has been brought to a full stop by use of the service brake) as long as the clutch is disengaged. They consist essentially of a check in the fluid line just ahead of the master cylinder and maintain the pressure as long as the clutch is held out of engagement. With this device in the hydraulic system the driver can remove his foot from the brake and use it on the accelerator as the clutch is engaged.

Servicing Front-End Alignment, Steering Systems, and Brakes. — Perhaps the most important units of a car from a service viewpoint are the steering system and the brakes. This is particularly true from a safety point of view. It is especially important, therefore, to be accurate and careful when servicing these units as there are so many variables to consider.

Steering and Front Ends. — The factors that affect steering are the steering gear, linkage and the front-end alignment.

Steering gears generally have three adjustments: one for backlash between the gears, which usually is accomplished by turning an eccentric sleeve or washer; one for end play of the worm due to loose bearing adjustments, which is controlled by an adjusting collar at the upper end of the worm, by shims, or by an adjusting screw and lock nut at the lower end of the worm; and one for end play of the cross shaft, which is controlled by an adjusting screw and lock nut, or by shims between the gear housing and cover plate.

Adjustment for backlash should be made with the steering gear in the center position and with the drag link disconnected. Although most adjustment specifications call for practically no free play, it is best to refer to the service manual of the car being repaired before adjusting for backlash.

If it is necessary to disassemble the steering-gear parts, they first should be washed thoroughly in gasoline; then the gears, bearings, and bushings should be inspected for wear, replacing them if necessary. The housing should be refilled with the specified lubricant. Before re-connecting the drag link, the steering wheel should be turned through a complete cycle. There should be no binding in

this operation. Some manufacturers specify a maximum load required to turn the steering gear through the center position. It is measured by pulling on a scale attached to the bottom of the steering-wheel rim.

Camber, caster, toe-in, and king-pin inclination must all be within the limits specified by the car manufacturer in order to have safe and easy steering.

These adjustments are made, with various kinds of equipment to check the results, with the full weight of the car on the ground. Before checking these adjustments, the tire pressure should be brought to the specified value. At this time the wheel-bearing adjustment should be checked against specifications. The king pins and their bushings should be inspected for excess play, and the springs should be checked for breaks or sags. Incorrect toe-out on turns often is caused by bent steering arms. If the toe-out is not correct, the front tires will wear excessively when the car is turning corners.

Following is a list of steering troubles and their causes:

1. Hard steering
   - Low or uneven tire pressure
   - Lack of lubrication in the steering linkage or king-pin bushings
   - Tight ball-and-socket joints
   - Tight steering gears
   - Steering arms or knuckles bent or twisted
   - Improper caster, camber, toe-in, or king-pin inclination
   - Steering-gear shaft or tubing bent
   - King pins tight in their bushings
2. Looseness in steering
   - Front wheel bearings loose or worn
   - Loose linkage
   - King-pin bushings, bearings, or pins worn or loose
   - Steering wheel loose on post
   - Loose adjustments in steering gears
3. Pulling to one side on using brakes
   - Low or uneven tire pressure
   - Brakes not properly adjusted, or worn or dirty lining
   - Steering knuckle bent
   - Improper caster
4. Shimmy
   - Wrong or unequal camber or caster
   - Wrong toe-in

Weak springs
Uneven tire pressure
Looseness in the steering mechanism due to wear or poor adjustment
Faulty shock absorber, due to mal-adjustment or lack of fluid
Tires, wheels, or brake drums out of balance
Loose spring U-bolts

5. Wander (difficult to keep the car in a straight line, not shimmy)
   Low or uneven tire pressure
   Steering gears adjusted too tightly or loosely
   Worn steering gears
   Wrong caster or camber
   Wrong toe-in
   Rear axle out of line
   Tight tie-rod ends or ball-and-socket joints
   Tight king pins in bushings
6. Wheel tramp (up and down motion of front wheels — together or separately)
   Tires, wheels, or brake drums out of balance
   Shock absorbers improperly adjusted or dry

When steering troubles are encountered, it is best to check over all the possibilities just mentioned, since there is a great overlap of causes.

Too much stress cannot be placed on the importance of doing all front-end work accurately and carefully.

Servicing Brakes. — Brake maintenance may be divided into two headings:

1. Adjustment and repair of linings, shoes and drums.
2. Adjustment and repair of the hydraulic system or the brake linkage between the foot pedal and the brake shoes.

All the types of brake shoes and linings previously described have one main point in common — they must be properly adjusted and in good condition to be effective.

In many cases all that is needed is a minor brake adjustment, which simply means that the brake lining has worn a little and must be moved nearer to the drum by means of an adjusting screw, to obtain better braking. To insure that all the brakes hold equally, jack up all four wheels and adjust each brake so that there is an equal drag on all four wheels when the brake pedal is held partially depressed.

A major brake adjustment first involves removing the wheels and brake drums, then inspecting the lining for wear, and the drums for

scores and out-of-roundness. If the drums must be turned down, factory specifications should not be exceeded as removing too much metal will weaken the drum. If the linings are glazed, greasy, or worn flush with the rivets, they should be replaced. A major adjustment includes also inspection of the hydraulic system or the mechanical brake linkage. If necessary, the master cylinder and the wheel cylinders should be honed and new pistons and rubber cups installed. Some manufacturers advise replacing the cylinders with new ones instead of servicing them. The system should be cleaned thoroughly with alcohol, by " bleeding " the alcohol through the entire system. Alcohol will not damage the rubber cups as will other types of cleaning fluid. After re-assembling the hydraulic system parts, the linkage between the brake pedal and the master cylinder piston should be adjusted so that there is free play as specified by the manufacturer. This adjustment assures complete return of the piston when the brake is released, thereby uncovering the compensating port so that it may do its duty. Only the hydraulic brake fluid recommended by the manufacturer should be used. After replacing and adjusting the brake shoes, the lines should be bled, one wheel at a time to remove air in the lines, with the bleeding tube immersed in a jar containing some brake fluid. The lines are bled enough when no more air bubbles are seen rising through the liquid deposited in the jar. Bleeding the lines insures that no air will be drawn back into the line on the return stroke of the pedal. The lines always should be bled with the brake drums in place; otherwise the pressure of the liquid will push the pistons out of the wheel cylinders.

Special equipment is available to assist in relining the brake shoes, turning down the drums, bleeding the lines, adjusting the brake shoes to proper clearance between the linings and the drums, and testing the effectiveness of the completed job.

Brake troubles can be classified as follows:

1. Pedal strikes the floorboard
   - Normal wear of lining
   - Low level of the brake fluid in the master cylinder reservoir
   - Leak in the hydraulic system
   - Air in the hydraulic system
   - Brake shoes not properly adjusted
2. Dragging brakes
   - Incorrect fluid, which swells and rots the rubber piston cups
   - Brake pedal has no free play. This condition possibly means that the master cylinder piston does not return all the way, thereby keeping the compensating port closed.

Clogged compensating port. This condition does not allow the fluid to circulate through the reservoir, causing pressure to be built up in the lines which may be high enough to keep the brakes partly applied.

3. One wheel drags
   Weak or broken brake-shoe return springs
   Insufficient brake clearance
   Loose front-wheel bearing adjustment
   Sticking piston cups or piston
   Clogged or kinked line
4. Car pulls to one side on application of the brakes
   Grease- or brake-fluid-soaked lining
   Loose wheel bearings
   Low tire pressure
   Loose backing plate
   Primary and secondary shoes reversed
5. Springy pedal
   Air in the hydraulic lines
   Poor shoe adjustment
6. Excessive pedal pressure required
   Poor shoe adjustment
   Improper lining
   Oil-soaked lining
   Partial lining contact, due to poor anchor-pin adjustment
7. Brakes too sensitive
   Poor shoe adjustment
   Loose backing plate
   Grease on lining
   Scored drums
   Improper lining

All of the foregoing troubles can be remedied either by a minor adjustment, or by a partial or thorough going over. Manufacturers' specifications always should be followed and new parts recommended by them should be used.

When making a major adjustment on mechanical brakes, the linkage between the brake pedal and the brake-shoe operating levers always should be disconnected. All joints should be lubricated, the cross shaft equalized, and the brake-rod clevises adjusted so that the brake rods just reach the shoe operating levers without any lost motion. This work should be checked with car specifications.

CHAPTER XXVI

CHASSIS LUBRICATION

Proper chassis lubrication is just as essential to satisfactory motor vehicle performance as is engine lubrication (which was fully covered in Chapter IX). Results just as disastrous as those arising from lack of engine lubrication will accrue from failure to lubricate the chassis properly — even though they may take much longer to materialize.

About 34 different points on the modern passenger car chassis require lubrication, the greatest number on any car being about 45 and the least number, 21. The actual number varies with the design and construction of the particular make (Fig. 190). Some of the points require lubrication oftener than others, while the character of the lubricant most suitable for application varies too, as the chart indicates. No single " universal " lubricant has yet been devised, although car engineers and petroleum technicians are working in that direction and in recent years have reduced the number of different lubricants necessary to lubricate a chassis properly.

Lubricants for use in chassis parts may be classified generally in three groups:

1. *Gear Lubricants.* — Gear lubricants are made to withstand considerable pressure, to flow freely at fairly low temperatures, and to maintain their " body " at the relatively high temperatures under which they must operate. Their function is to cushion the hammering action which occurs between the teeth of meshed gears, to carry the load from one gear tooth to another and to lubricate the rubbing surfaces. The lubricant in gears also cleans and cools the rubbing surfaces of the gear teeth.

Gear lubricants made to withstand the above-normal gear tooth pressures characteristic of certain designs are called extreme pressure lubricants, while those designed for use in hypoid rear axle gears are commonly called hypoid lubricants.

Gear lubricants are graded according to SAE numbers, each number representing a particular specification set up by the Society of Automotive Engineers. The lightest gear lubricant for modern cars is SAE 80. This is used for extremely cold weather conditions. SAE 90 is suitable for ordinary winter temperatures and, in some in-

stances, is recommended for summer use. SAE 140 is a heavier type for normal summer use, while SAE 250 is an extremely heavy lubricant suitable only for very special conditions.

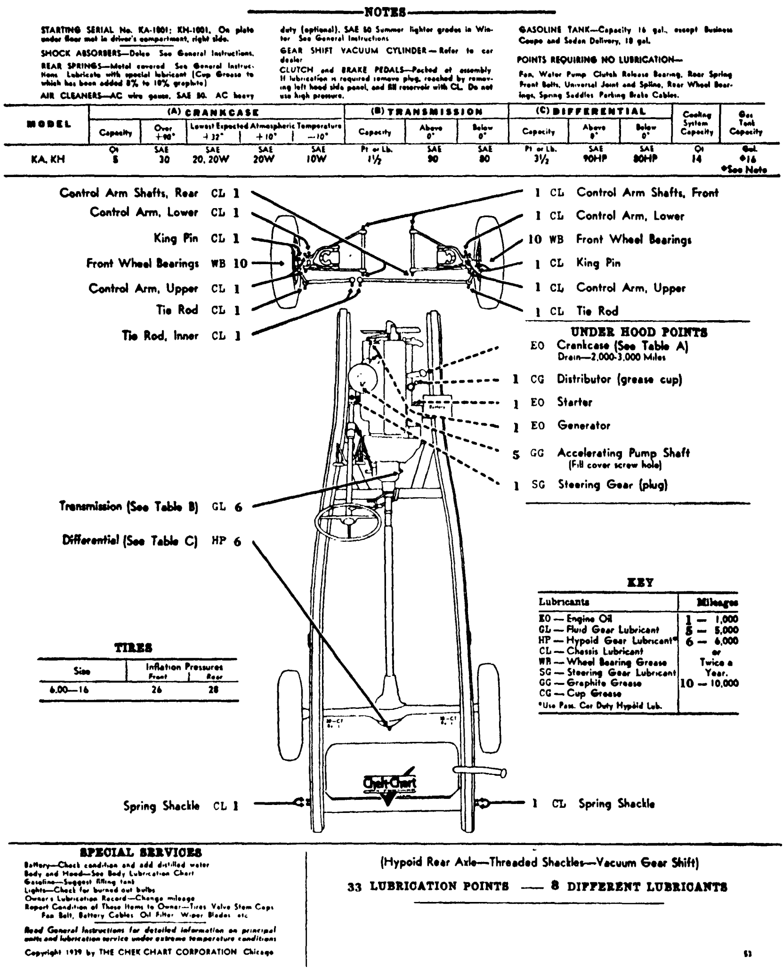


Fig. 190 — Chassis points to be lubricated on a typical passenger car

2. *Chassis Lubricants.* — The term "high-pressure grease" is often applied to the type of lubricant designed for general points on the chassis because it is usually applied with a "grease gun" to the grease-gun fittings with which most chassis are equipped. This general chassis lubricant may be a soft non-fluid or a semi-fluid and usually embodies a lime or aluminum base, which gives it good spreading qualities, load-carrying ability, and resistance to water.

3. *Special Lubricants.* — A wide variety of special lubricants are available for particular purposes, in addition to the general types just described. A short-fiber grease, for example, usually made of sodium soap, is made especially for wheel bearings, where its high melting point and stringy nature renders it particularly adaptable. A long-fiber grease constructed to resist centrifugal force action and prevent the soap base from separating from the oil is specially designed for application to universal joints. Sometimes a medium-fiber grease serves for both wheel bearings and universals. Another special type grease is designed for the operating conditions peculiar to the older type of gland-packed water pump; a graphite grease is made for springs; a special oil for starters and generators, etc.

Each chassis unit has its own special lubrication requirements, and these requirements have been the basis for development of the various kinds of lubricants mentioned. Each car manufacturer makes specific recommendations as regards the proper lubricant for each chassis point on each of his models. Those specifications should be followed carefully when the job of lubricating a particular chassis is undertaken. A few general observations as regards the lubrication requirements of the various chassis units will indicate the nature of the problems involved.

Transmission Lubrication. — A bath of lubricant, in which the transmission gears operate, prevents metal-to-metal contact which would generate so much heat that the gear teeth would be burned away, and lubricates the ball or roller bearings in the transmission. Proper lubrication of the transmission and transmission devices, therefore, is extremely important. Different designs have different requirements.

Synchromesh transmissions and self-shifting transmissions of the "Hydra-Matic" type, free-wheeling units and some overdrive units require fluid gear lubricants or extreme-pressure lubricants. Most car makers, however, recommend engine oils for transmissions with overdrive.

Different lubricants are needed in the transmission at different seasons of the year — and it is important that the different types should not be mixed.

Transmission lubricant level should be inspected every 1,000 miles and refilled if necessary. Transmissions should be drained, flushed, and refilled approximately every 5,000 miles — or at least once each season.

Universal Joint and Propeller Shaft Lubrication. — Some universal joints are provided with a fitting for external lubrication;

others (the roller-bearing type) must be disassembled and packed with lubricant by hand. Different constructions and different manufacturer recommendations make it necessary to consult manufacturers' specifications before applying lubricants to universal joints. For propeller shaft bearings, chassis lubricant, wheel bearing grease or engine oil usually is recommended, although some types are packed at the time of original assembly and require no further lubrication during their life.

Rear-Axle and Differential Lubrication. — Particular attention to rear-axle lubrication is warranted because the complex character of these units makes failure of parts exceptionally expensive and inconvenient. Most of the rear-axle parts run in a bath of lubricant, and proper lubrication consists chiefly of checking at specified intervals to see that this bath is maintained at its proper level. As in the case of the transmission, lubricants of different viscosities are needed in the rear axle at different seasons of the year.

Changing rear axle lubricants is a simple matter when the rear axle is provided with a drain plug — but this is not always the case. When no drain plug is provided, it is usually possible to remove one of the cap screws at the bottom of the differential cover and allow the lubricant to drain out. In some designs, the differential cover is welded to the housing. In such cases, the lubricant must be pumped out with a syringe or similar device.

Proper lubrication of differentials involves inspection at 1,000-mile intervals, refilling if needed, and a complete draining, flushing and refilling about every 5,000 miles or once each season.

Front Wheel Suspension Lubrication. — In the independently sprung front wheel constructions common to most modern passenger cars, the tie rod usually is divided into two or three parts, all the ends of which commonly require lubrication. The intermediate steering arm in some designs requires lubrication, while in others it is packed with lubricant at the time of original assembly and needs no further attention. The inner ends of some upper control arms require lubrication, and particular attention should be given to king-pin lubrication in practically all constructions.

Some independent front wheel suspensions are provided with wicks and require a specific grade of oil or gear lubricant.

Wheel Bearing Lubrication. — Front and rear wheel bearings are lubricated differently.

To lubricate the front wheels, the wheel hubs usually are removed and the bearings are repacked, either by hand or with suitable special equipment.

Lubrication of rear wheel bearings is accomplished in a variety of ways, depending upon the construction of the particular unit. These constructions fall into four general categories: (1) those which are automatically lubricated from the differential; (2) those equipped with sealed ball bearings packed with lubricant at the time of assembly and requiring no further attention; (3) those in which the bearings are lubricated by means of a compression grease cup or fitting at each end of the axle tube; and (4) those in which the bearings are lubricated by hand after removal from the car.

Over-lubrication of rear wheel bearings should be avoided to prevent the lubricant from getting on the brakes.

Spring Lubrication. — If springs are uncovered, they may be lubricated by spraying or painting with a penetrating oil. Such oil will work in between the leaves, provide lubrication and prevent squeaks.

Covers for springs are provided on many cars to keep the lubricant in and to keep out water and dirt. When springs are thus enclosed, they are usually lubricated through a small hole located on the under side of the spring cover. Some covers, however, have a screw plug for insertion of the lubricant.

Graphite grease is usually recommended for lubrication when springs are covered, but some car makers suggest a standard chassis lubricant and others a semi-fluid grease which does not contain graphite.

Brake Lubrication. — Lubrication of the flexible brake cables used on many modern cars is necessary only at intervals of 5,000 to 10,000 miles. These flexible conduits sometimes are provided with plugs or fittings to facilitate lubrication. Usually this is not the case, however, and at least partial disassembly or the use of special tools is necessitated.

Brake vacuum cylinders, which appear on some cars, have plungers and pistons which need periodic lubrication. Usually a light engine oil is injected through a plug at either or both ends of the cylinder.

Shock Absorber Lubrication. — Most shock absorbers on modern cars are of the hydraulic type. While several different designs are used, all operate on the same general principle of forcing fluid through a small hole. The requirements of the various constructions are quite different and fluids of different characteristics are used in each.

Many shock absorbers must be removed from the car to permit refilling, and in many cases special tools are necessary. The actual process of refilling consists simply of filling the unit with the kind of fluid recommended by the manufacturer of the particular car.

Different shock absorber fluids must not be mixed with one an-

other. If they are, the mixture may thicken or separate, thus making the unit function in a thoroughly unsatisfactory manner.

Clutch Lubrication. — The dry-type clutch common to most passenger cars requires no lubrication except for the clutch release bearing — and then only when the bearing is not permanently packed at the time of original assembly.

The wet type requires periodic attention. A plug in the flywheel is provided for draining and refilling the clutch housing. This operation should be done every 5,000 miles.

Because of the great variety of spring pressures and sizes in clutch release bearing types, designs and reservoir sizes, a great variety exists in the lubricants recommended for these units. Some require engine oil, some wheel bearing grease, some chassis lubricant, some fluid gear lubricant, and some require cup grease.

Over-lubrication of the clutch release bearing may force some lubricant onto the clutch facings and result in slipping.

CHAPTER XXVII

MOTOR FUELS

Petroleum. — Crude oil or petroleum is the principal source of present day motor fuels. It occurs together with natural gas beneath the surface of the earth, from which it is obtained by drilling wells. This crude oil is sometimes thick like tar, sometimes oily and heavy like amber-colored cream, and sometimes light and volatile like the gasoline which it yields. In color it ranges from almost black, yellow, or brown through shades of green to colorless. Petroleum has been found on every continent and is produced on a commercial scale in some 25 countries, but the United States is by far the most important oil producer.

Petroleum is composed principally of organic compounds which are known as hydrocarbons because they contain only the elements of hydrogen and carbon. It generally contains small quantities of sulfur, water, and other impurities as it comes from the earth. Because there are so many different ways in which hydrogen and carbon can combine with one another, petroleum contains a wide variety of hydrocarbons, and all petroleums are by no means identical in composition and properties. These hydrocarbon constituents may be gases, liquids, or solids, and the relative proportions of each type in the crude oil determine its characteristics. The job of the refiner is to sort out the various groups, or "fractions," of crude oil, polish off the rough edges, and deliver them to the market under their appropriate name of gasoline, kerosene, lubricating oil, fuel oil, asphalt, etc. He does this by means of heat and pressure with or without the use of chemicals.

Production of Gasoline. — Gasoline is the lightest, or, as it is more often termed, the most volatile liquid petroleum fraction. All material boiling up to about 400 F is generally considered to be in the gasoline boiling range. There are many different kinds of gasoline named according to the method by which they are made from crude oil.

1. Natural Gasoline. — It has already been mentioned that petroleum is associated in the earth with natural gas, and that the material taken from oil wells is a mixture of these two products. By compressing this natural gas, a very volatile liquid is obtained which is known as natural gasoline. Other methods of removing the natural

gasoline are known and used. The most recently developed one utilizes refrigeration. By cooling the natural gas to a low enough temperature, the gasoline condenses, just as steam on cooling condenses into water. About 7% of all the gasoline produced in this country is natural gasoline.

2. Straight-Run Gasoline. — Crude oil is a mixture of compounds of varying weight, or volatility, each of which has its own boiling point. The constituents of crude oil vaporize on heating in the order of their boiling points. Gasoline, being the lightest liquid material, boils off first, then kerosene, then gas oil, lubricating oil, and fuel oil, leaving a heavy residue from which asphalt and tar can be made. This process is known as distillation and is usually carried out at atmospheric pressure. As the vapors are formed, they are collected and condensed in separate groups according to the temperatures. These groups are, then, the various fractions of the crude oil. The gasoline obtained by distillation is called straight-run gasoline. It should be apparent that the properties of such a gasoline are entirely dependent upon the properties of the crude oil from which it was distilled. An average crude oil will yield about 25% of straight-run gasoline. At present, straight-run gasoline constitutes about 43% of the total gasoline production in this country.

3. Cracked Gasoline. — With the growth of the automotive industry during the 1915–1920 period, the demand for gasoline increased to such an extent that it could no longer be met economically by natural and straight-run gasoline alone.

Accordingly, the thermal cracking process was developed which, by increasing the yield of gasoline from crude oil, added to the motor fuel supply and at the same time conserved the petroleum resources of the United States. In thermal cracking, high temperatures and pressures are applied to the heavier petroleum fractions remaining after the straight-run gasoline and other desirable constituents have been boiled off. This treatment breaks the heavier fractions down into materials in the gasoline boiling range. Gasoline so produced is called cracked gasoline. Due to the heat and pressure treatment, it has a different chemical composition than the straight-run gasoline from the same crude oil source. Although cracked gasoline at first was thought to be inferior to straight-run gasoline, it was later found to be a superior fuel for automobile engines. Because of this, increasing quantities of straight-run gasoline are now being cracked.

When the material charged to the cracking unit is straight-run gasoline, the process is known as reforming, and the product is called reformed gasoline. Reformed gasoline like cracked gasoline has a

different chemical composition than the straight-run material. Thermally cracked and reformed gasolines now constitute about 49% of the total gasoline production in the United States.

Within the past few years, a new method of cracking has been introduced which uses a catalyst as well as heat and pressure to effect the conversion. To distinguish this process from the purely thermal one described above, it is called catalytic cracking, and the product is known as catalytically cracked gasoline. The catalytic action not only permits the use of lower temperatures and pressures, but also controls the chemical reaction more closely so that the product is of a higher quality. A catalyst is defined as a compound which aids or controls a given reaction without itself being changed or consumed in the conversion process. Thus, it can be used over and over again. Straight-run gasoline can also be reformed by catalytic means, and it is then known as catalytically reformed gasoline.

4. Polymer Gasoline and Alkylate. — In the operation of the distillation, cracking, and reforming processes, a great deal of gas is formed. For a long time this gas was considered a waste product and was used as a fuel for the refinery furnaces. Within the past few years, however, it has been found that certain hydrocarbon constituents of these gases can be made to react with one another under suitable conditions of heat and pressure, with or without a catalyst, to yield a liquid product boiling in the gasoline range. The products of these reactions are known as polymer gasoline and alkylate, respectively, depending upon whether like hydrocarbon gases or unlike ones have been joined together to yield the liquid product. These processes are just the opposite of cracking since the products are built up from gases rather than formed by the destruction of heavier crude oil fractions.

5. Commercial Motor Fuel. — Commercial motor fuels are generally blends of these different refinery gasolines. The amounts of these various materials used in the final motor fuel blend is governed by the expense of production as well as by the blending characteristics of the individual products. Comparatively speaking, straight-run gasoline and thermally cracked gasoline are the least expensive to produce and are produced in the greatest quantity. Consequently, they constitute the greatest proportion of commercial motor fuels. Small amounts of natural gasoline, polymer gasoline, catalytically cracked gasoline, and alkylate are sometimes added to improve certain characteristics in the final motor fuel blend. Just what these characteristics are and how they are improved will be discussed in the next section.

In general, three grades of fuel are marketed for automotive use. They are known as premium grade (usually Ethyl), regular grade, and third-grade fuel. There is a general gradation in quality and cost from the premium grade through the third grade. Different grades of motor fuel are necessary to satisfy the demands of the various kinds of motor vehicles and the different types of service. Aviation fuels are, in general, of a much higher quality than the average automotive fuel and cost considerably more.

Properties of Gasoline. — Motor fuels are in many cases marketed under state and federal specifications. These specifications cover the major characteristics of gasoline, namely, volatility, antiknock quality, sulfur content, gum content, and purity. All of these properties are related in one way or another to the operation of the motor fuel in the engine. As engine design is constantly improved, refiners must improve their motor fuels so that they will operate satisfactorily in the new engines. Specifications, therefore, are not static but continually change with the progress in fuels and engines.

1. Volatility. — Volatility is one of the most important characteristics of gasoline. It may be defined as the tendency of the motor fuel to pass from the liquid into the vapor state at any given temperature. The volatility of the gasoline influences the ease with which the engine will start and the behavior during the warming-up period as well as the behavior during normal operation. The volatility of a gasoline is indicated by its distillation characteristics. The distillation is carried out according to a standard procedure in which 100 cc of the gasoline are heated in a flask at a constant rate of temperature rise, and the vapors are condensed and collected. The temperatures at which each successive 10 cc of gasoline distill over are noted, and the volatility of the gasoline is discussed in terms of these temperatures. Since 100 cc are used in the distillation, the 10 cc fractions represent corresponding percentages of the gasoline, and the temperatures are known as 10%, 20%, 30%, etc., points.

The 10% point is generally accepted as a measure of the cold-starting abilities of the gasoline. The lower the 10% point, the greater the proportion of material which will vaporize readily at low engine temperature. Engine behavior during the warming-up period is usually thought to be related to that part of the distillation curve lying between the 15% and the 45% points, or even as high as the 70% point. Behavior during normal operation is related to the overall volatility of the gasoline. Some use the 90% point as a criterion of this overall volatility; others prefer a combination of 10%, 50% and 90% points. In either case, such relations cannot be

defined more definitely than to say that, the lower the temperatures of the various percentage points, the more volatile the gasoline.

The trend in the volatility of gasoline during the past 20 years has been toward more volatile fuels because experience has shown that, the more volatile the fuel, the more uniform the distribution of the gasoline to the various cylinders and the smoother the operation of the engine.

One disadvantage of very volatile fuels should be mentioned. When a fuel has a very great tendency to vaporize at normal atmospheric temperatures, it may form so much vapor in the fuel system of the engine that it will clog the lines and actually kill the engine. This condition is known as vapor lock. It is encountered most frequently in very warm weather. The tendency of gasolines to vapor lock is controlled best through regulation of the vapor pressure and the 10% point. In winter, when lower atmospheric temperatures prolong the warming-up period of the engine, it is important to have more volatile fuels. Refiners generally increase the volatility of the fuels they market in winter weather by adding additional quantities of natural gasoline.

2. **Antiknock Quality.** — Every motorist wants to get as much power and speed and as many miles per gallon of gasoline as he can. Engines must be designed to give these advantages, but improvements in engine design are limited by the antiknock quality of the fuel available for their use. During the period from 1927 to 1938, the combined efforts of the automotive engineers and the petroleum technologists have given the motorist a power increase of 45% and a 20% improvement in economy.

Antiknock quality is measured by an arbitrarily selected "yardstick" called the octane scale. The octane number of the motor fuel is determined by matching it against mixtures of normal heptane and iso-octane in a test engine under specified test conditions until a mixture of the pure hydrocarbons is found which gives the same degree of knocking in the engine as the gasoline being tested. The octane number of the gasoline is, then, the per cent of the iso-octane in the matching iso-octane-normal heptane mixture. For example, a gasoline rating 75 octane number is equivalent in its knocking characteristics to a mixture of 75% iso-octane and 25% normal heptane. Thus, by definition, normal heptane has an octane number of zero and iso-octane has an octane number of 100.

The tendency of a fuel to knock varies in different engines and in the same engine under different operating conditions.

We have mentioned in preceding paragraphs that antiknock qual-

ity is rated by the degree of knocking which the fuel produces in a test engine. What is knocking?

If a fuel is not of sufficiently high antiknock quality for the engine in which it is being used, it will burn too rapidly in the cylinders for satisfactory utilization, as explained in Chapter IV. These explosions can be heard as a metallic " ping," and the condition is commonly called knocking. If knocking is allowed to persist or become too severe, power is wasted. Under extreme conditions, mechanical failure may result.

The major importance of the newer refining methods which were discussed in the previous section lies in the fact that they produce fuels of greater antiknock quality. At the present time, the average octane rating of regular-grade gasoline is about 74. Straight-run gasoline averages about 50 to 55 octane number; thermally cracked gasoline ranges from about 60 to 80 octane number. By adding a suitable antiknock compound, such as tetraethyllead, these gasolines may be blended to reach the octane level of present-day regular and premium-grade motor fuels. However, experts are already prophesying road octane ratings of 85 to 90 for regular grade and 95 for premium-grade motor fuels.

The antiknock quality of any given motor fuel blend can be further increased by the addition of antiknock compounds, i.e., materials which are able to slow down the combustion of the fuel and so prevent the " ping." Only relatively small quantities of these compounds need to be added to a fuel to produce this effect. The most widely used antiknock compounds are organic derivatives of some of the common metals, of which tetraethyllead is the outstanding example. About 80% of all motor fuel sold in the United States today contains tetraethyllead in quantities varying up to a maximum of 3 cc per gallon. Since tetraethyllead will raise the antiknock quality of all hydrocarbons, it is reasonable to believe that it will play a large part in making the high octane fuels which will be needed in the future.

3. Sulfur Content. — All crude oils contain sulfur, some more than others. Part of the sulfur is carried through the refining operation to the gasoline. Most of this sulfur exists as organic sulfur compounds although some free sulfur may be found in certain crude oils. Too much sulfur is liable to corrode cylinder bores, bearing surfaces, and exhaust systems. In some cases, therefore, the refiner is forced to remove harmful quantities. Except in a few cases, sulfur content has been held rigidly to a maximum of 0.1%.

4. Gum Content. — When gasoline is exposed to air, some of the hydrocarbons are oxidized into sticky gum. This gum is responsible

for a number of operating difficulties — stuck valves and piston rings, excessive engine deposits, coated intake manifolds, clogged carburetor jets, etc. By proper chemical treatment and/or the addition of a suitable gum inhibitor or anti- oxidant, the gumming tendencies of gasoline can be controlled so that the fuel will not give trouble when used in an engine.

5. Purity. — Naturally, dirt and grease, and traces of chemicals and water must be removed from gasoline before it can be sold as a motor fuel. Reputable refiners are very careful to see that no such foreign materials get into or remain in their gasolines. However, it is very easy for extraneous materials to contaminate gasoline after it leaves the refinery, and thus the retail marketer is also responsible to some extent for the purity of the product he delivers to the public.

Gasoline in Engine Operation. — As the name " internal-combustion engine " implies, the fuel is burned in contact with the moving parts of the engine. The products of the combustion are, therefore, very important. There is no opportunity to remove ashes as in the case of burning coal under a steam boiler. All the products of combustion which are not in a gaseous or vapor form may be left behind to interfere with the moving parts of the engine. For this reason, the motor fuel must be practically chemically pure to insure complete combustion with the minimum amount of residual products. Chemical impurities, such as sulfur, may leave acid residues in the combustion chambers which may seriously affect the efficiency of the engine. Likewise, excessive gum may tend to cause carbon to build up in the combustion chamber. Fuel improperly mixed with air by the carburetor or a fuel of too low volatility will not burn completely and, thus, will leave excessive deposits. Any or all of these factors will seriously reduce the operating life of the engine.

Gasoline Substitutes. — The ideal automobile fuel must have these six major properties:

1. It must be plentiful
2. It must be cheap
3. It must be easy to handle
4. It must be easily vaporized
5. It must have a high content of energy
6. It must be knock-free

Gasoline, as now made from petroleum, fills this bill pretty well. However, in some countries where petroleum is scarce, it has become important to find substitutes for petroleum gasoline. Germany, Italy, Great Britain and France have very little petroleum within their national boundaries, and have taken the lead in the develop-

ment of substitute motor fuels. The principal substitutes are motor fuels made from coal by carbonization or hydrogenation, alcohols made from grain or other farm products, compressed gas derived from the burning of coal or wood, and benzol, a liquid byproduct of coke ovens and gas works. Each of these falls short of the demands of an ideal fuel on one or more points. Coal carbonization or hydrogenation is a very expensive method for producing motor fuel. Alcohols have a relatively low energy content. Coal or wood gases are bulky and awkward to handle. In order to have a sufficient fuel supply, it is often necessary to carry a trailer with reserve fuel tanks of compressed gas. Benzol is expensive, and its production is limited by the activity of the coke ovens and gas works of which it is a byproduct. Up to the present, the use of such substitute fuels can be justified only when there is a deficiency in petroleum or when some special or unusual economic conditions are involved.

Other Motor Fuels from Petroleum. — Petroleum fractions heavier than gasoline can be used as fuel for certain types of motors. Low-compression engines, such as are found in the older types of farm tractors, will operate on kerosene or tractor distillate. But even tractors are rapidly being converted to high-compression engines which will require gasoline as fuel because the consequent gains in efficiency and power more than offset the higher cost of the fuel.

Compression-ignition engines, more commonly known as diesel engines, are also constructed to operate on heavier fuels. There are two classes of diesel fuel. High-speed diesel engines, such as are found in large transport trucks and diesel trains, require a light diesel fuel which is similar to domestic oil or furnace oil in volatility. The fuel requirements of this type of engine are very exacting, especially with respect to distillation range and ignition quality. Ignition quality is a measure of the combustion speed and, therefore, is analogous to the octane number of gasoline fuels. However, diesel engines require a fuel which has fast-burning tendencies since the fuel is injected directly into the cylinders and is ignited by the heat of compression rather than by an electric spark. This is just the opposite of the requirements of the spark-ignition gasoline engine. The large industrial and marine diesel engines operate at much lower speeds than the automotive and train diesels and are able to burn a much heavier or less volatile fuel. The ignition quality requirements of this engine are not exacting. Therefore, a much less expensive fuel can be used.

CHAPTER XXVIII

REFERENCE DATA FOR THE REPAIRMAN

There is a wide gap between knowledge of the function of the various parts of an automobile and the ability to make all the parts of a particular vehicle operate properly. Even a clear understanding of what may go wrong with each of these parts and the cause of the trouble does not nearly bridge that gap. Actual experience in repair techniques is essential for those who would become competent repairmen, whether in working on their own cars, in working professionally in maintenance shops or in emergency work on military assignments.

Whatever may be the individual's opportunity for acquiring such actual repair experience, his advance will be facilitated greatly by knowledge of where to turn for specific and detailed data regarding particular makes and models.

Accumulation of information about specific cars and parts solely from chance contacts with a long series of immediate repair jobs is a labor of many years. Knowing where to turn for already compiled information will shorten and facilitate the task materially. Almost every conceivable sort of data has been compiled regarding the modern automobile. Learning more about these various information sources and how to tap them will reduce to a minimum wasted time and needless mistakes. The ablest repairman is the one who not only uses the specific knowledge he has been able to cram and keep in his own head, but also knows how to tap the vast resources of constantly changing information regularly being compiled by others.

The purpose of this chapter is to indicate the sort of information that is available in ready-reference form and to suggest how such information can be obtained when needed.

Factory Service Manuals. — Every automobile factory issues each year a service manual describing in detail repair procedures on each part of the models manufactured that year by its own organization.

Faced with a repair job on a 1942 Salient Six, the most helpful piece of written material to have at hand is the Salient Six service manual for 1942. In the normal course of events, these comprehensive — and relatively expensive — factory service manuals are sup-

plied automatically to all authorized dealers. Most factories today will supply a copy of their current service manual to any regularly established independent repair shop free upon request or for a small charge. Individual owners usually are content with the less detailed " owner's service manual " which comes with the car at the time of purchase. Mechanically minded owners usually can obtain a copy of the comprehensive service manual, however, upon request to the factory, although a charge of perhaps a dollar or two is made in a few cases. The same thing holds true of trade schools, educators and other directly interested groups. Some factories will supply complete service manuals only upon the recommendation of their local dealers.

Despite the great value of the factory service manual, its use by others than dealers for the particular make is subject to certain practical limitations among which are: (1) it may take a week or two for a response to a request to arrive; (2) not all factories are equally interested in filling such requests; (3) to have such manuals available in advance for immediate use would mean the accumulation of at least one manual for *every* make for *every* year — which would mean careful preservation and filing facilities frequently impractical for independent repair shops. Where any considerable amount of work is being done on a given make, however, accumulation of factory service manuals for that make is not only practical but highly desirable.

Ready Reference Compilations. — To meet the needs of repair groups which are interested in many makes and many models, some commercial publishers issue and sell regularly compilations of service information covering all makes and models, usually including such back years as are most likely to be met with in practical repair shop operation. Some of these cover all phases of service and repair; some concentrate on specialized phases such as lubrication.

Such a general compilation, for example, is MoToR's Factory Shop Manual, brought up to date and published annually by the trade publication MoToR, 572 Madison Avenue, New York. This comprehensive manual gives step-by-step procedure for repairing cars. It contains a chapter for each make of car. In that chapter, all the service information issued by a given car manufacturer is digested compactly. It is a complete book on procedure. (It does not tell how to cure a missing cylinder or how to use a reamer.) In 1941 its price was $3. It contains about 500 large pages and is profusely illustrated.

A good illustration of a specialized commercial service is that of-

fered by Chek-Chart Corp., 624 S. Michigan Avenue, Chicago. Chek-Chart is a system for providing accurate instruction to operators of lubrication stations for proper lubrication of passenger cars and light trucks. Foundation information is issued yearly in a 192-page volume of car diagrams, each giving full details regarding capacities of crankcase, transmission, differential, cooling system, etc., together with seasonal motor oil and grease lubricant recommendations in approved temperature ranges. The information is kept up to date by a monthly bulletin service. Chek-Chart is obtainable in syndicated form at $12 per year. Special editions prepared for leading oil companies are available only from those oil companies and are sometimes sold, sometimes provided as part of oil-company station equipment and sometimes become part of a specific order for oil or grease. Also available is a Chexall Accessory Blue Book providing data on fan belts, fuses, tires, batteries, spark plugs, radiator hose, oil filters, lamp bulbs, windshield-wiper blades, battery cables, etc. (Price $3.50). This is also available in special form through a number of oil companies.

Sometimes, as sales promotion, parts or accessory manufacturers will produce general service procedure manuals (in addition to their regular service manuals covering only the servicing of their own products). When this is the case, reputable repair shops are more than welcome to these manuals and often will receive them unsolicited.

The few examples which have been cited serve to illustrate the type of material which is available and to emphasize the fact that a few hours spent in seeking and consulting source material may save many days of mental and physical effort — as well as help materially to insure a better result from a given expenditure of effort.

Trade Publications. — No industry in the country is better served by effective trade publications than is the automotive maintenance field. The list of periodicals devoted exclusively to problems of automotive repair procedure is well supplemented by an important group of publications devoted partly to service and partly to merchandising methods.

Information about new models, detailed changes in old models, new service methods, new service tools, service procedures and a mass of similar information is brought by these publications — regularly, promptly, and accurately. Depending upon the particular type of work being engaged in, one or another of these publications will be of most value. No working service man can hope to keep up with the constant and rapid changes in designs, equipment and

service techniques unless he reads regularly at least one trade publication.

Most of these publications are available for examination in public libraries, where they may be studied and where the individual student may choose the publication or publications best suited to his needs. Having selected and subscribed to the publication chosen, he should read each issue carefully. There is much more to be gained from a thorough and regular reading of a single publication than from irregular and casual perusal of many.

Following are some of the trade publications likely to be of value to the service man:

Southern Automotive Journal (monthly)
Atlanta, Ga.
Automotive Service (monthly)
Detroit, Mich.
MoToR (monthly)
New York, N. Y.
Brake Service (monthly)
Akron, Ohio
Autobody and the Reconditioned Car (monthly)
Cincinnati, Ohio
Automobile Digest (monthly)
Cincinnati, Ohio
Motor Age (monthly)
Philadelphia, Pa.

CHAPTER XXIX

LIGHT MILITARY TRUCKS

Design Features and Differences from Conventional Vehicles

In design, construction, and operation, modern light military trucks follow *in general* the same principles as do the conventional types of light motor vehicles discussed in the preceding chapters. The severe requirements of modern warfare, however, necessitate a number of modifications. Whereas most conventional vehicles are designed to operate over roads and to negotiate only reasonable grades, military trucks must be designed for service, not only over roads but also through cross-country terrain, sand, gravel, deep mud, streams, trenches, and ditches.

The fundamental modifications necessary in the design of conventional vehicles to adapt them for military service are made to permit the trucks to meet these conditions. Such modifications are the provisions of all-wheel drive (four-wheel drive on all four-wheel trucks and six-wheel drive on all six-wheel trucks) to give maximum traction; installation of more powerful engines; employment of higher gear ratios and of an increased range of gear ratios; stronger springs; greater axle clearance; larger-diameter heavy-duty tires; and increased cooling capacity. Other changes that affect the fundamental chassis design only in a minor way include adjustable windshields, tow hooks and pintles, radiator and headlight brush guards, rollers, military-type bumpers, bullet-proof windshields, blackout lighting equipment, bullet-sealing tire tubes, and armor plate.

In order to obtain large quantities of military trucks quickly and efficiently when needed, the policy of the War Department has been to adapt existing commercial and passenger types of vehicles for military service, thus utilizing to best advantage the tremendous manufacturing capacity of the American automotive industry. This practice also simplifies servicing and maintenance of the military trucks since it assures an ample supply of replacement parts and of mechanics trained to service these designs. After the most suitable type has been selected for a certain military service, the necessary design modifications are made prior to production.

Fig. 191 — ¼-ton light reconnaissance car. Many basic units used in standard vehicles are used, but special carburetor and manifold enable powerplant to develop 61 hp at 3800 rpm. Radiator is protected by a heavy grille. Special gear set provides six forward and 2 reverse speeds and a lever permits driver to select four-wheel or two-rear-wheel drive at will. Windshield, hinged at bottom, can be folded forward

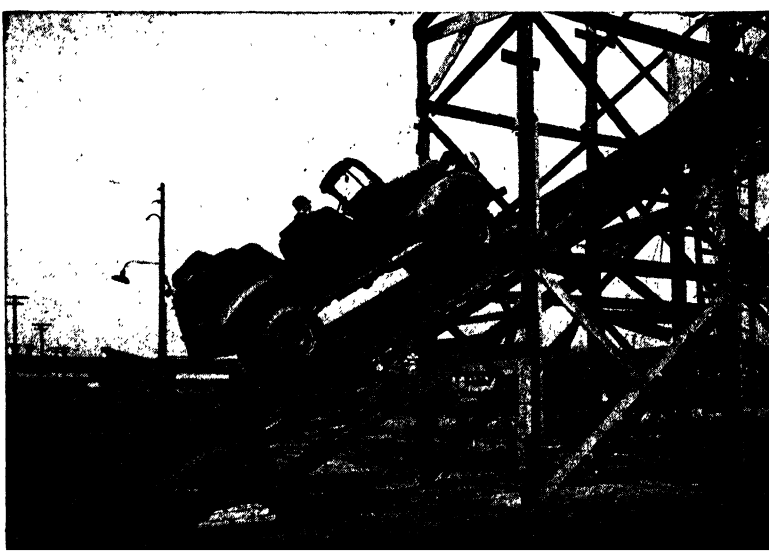


Fig. 192 — Eight-passenger ½-ton reconnaissance truck on grade-test ramp. The special body has a collapsible top, no doors, a heavy protecting screen or brush guard in front of the radiator and headlamps, and a channel-iron front bumper. The front-wheel drive of its four-wheel drive can be cut out when desired. The spare tire is carried on the left running board

Or, in the words of Major-General E. B. Gregory, U. S. Quartermaster-General, speaking at the 1941 Annual Meeting of the Society of Automotive Engineers:

"The present War Department policy for the procurement of motor vehicles is to limit acquisition to models in commercial production by two or more competing organizations, and available at reasonable prices. Any deviation required from standard models is held to a minimum to meet the essential military needs. The parts which make up unit assemblies have in many cases been standardized throughout the industry as a result of the activity of the SAE, and are procured as standard material for both new vehicles and replacement or maintenance purposes.

"The all-wheel drive principle has proven to be most desirable for army vehicles, and it has been adopted as standard by most of the great armies of the world. Originally used only on the larger trucks, the field of the four-wheel drive has been progressively widened. In 1938, we started using all-wheel drive on part of the ½-ton trucks and we have gone all the way in 1940 with all tactical equipment. In every case the result of the all-wheel drive has been performance far surpassing the expectation of the engineers."

U. S. military trucks are classified as ¼-ton, ½-ton, 1½-ton, 2½-ton, 4-ton, and 6-ton. Examples of all these types except the 4-ton and 1½-ton trucks are shown in the frontispiece of this volume.

The ¼-ton trucks (Fig. 191) are used as light-weapon carriers for the infantry, personnel, and troop carriers.

The ½-ton trucks are used as personnel and troop carriers, command and reconnaissance vehicles (Fig. 192), utility trucks, light cargo trucks, weapon and ammunition carriers, ambulances (Fig. 193), and prime movers of light cannon, such as the anti-tank gun. They are usually modified passenger vehicles (Fig. 192).

Trucks in the 1½-ton class are employed as light cargo trucks (Fig. 194), prime movers of light artillery, such as 75-mm field guns, engineer dump trucks, light repair trucks, and scout cars. Cargoes carried by this type of military truck include ammunition, communication equipment, rations, and baggage. They are of the four-wheel four-wheel-drive type, usually with dual rear wheels and tires.

The 2½-ton trucks are used as prime cargo carriers (Fig. 195), fuel tankers, troop-movement vehicles, repair trucks, animal carriers, searchlight transports, and prime movers for medium artillery (75-mm field guns and 105-mm howitzers). These trucks are of the six-wheel all-wheel-drive type with dual tires and wheels on

Fig. 193 — ½-ton military ambulance

Fig. 194 — Light cargo type of 1½-ton military truck under test. To pass, it is required to go up the 6-ft incline shown without losing speed

both rear axles. In many cases these trucks use the same axles and basic transfer case as employed by the 1½-ton four-wheel military trucks.

Among the uses for the 4-ton and 6-ton military trucks are those as prime movers for towing heavy field artillery (such as 155-mm howitzers) and anti-aircraft artillery (3-in. and 90-mm), as heavy cargo trucks, as field-servicing trucks, and tractor trucks for towing semi-trailers. They are always of the six-wheel all-wheel-drive type with dual wheels and tires on both rear axles.

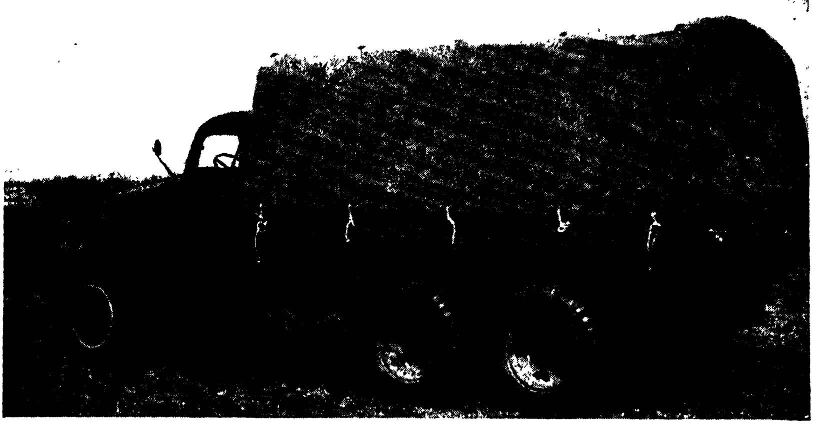


Fig. 195 — 2½-ton six-wheel all-wheel-drive military cargo truck

U. S. Army specifications require that military trucks must be able to go up a 60 to 65% grade with a full load (see Figs. 192 and 194); and make 40 to 45 mph on the level. (A 60% grade is one that rises 60 ft vertically for every 100 ft of horizontal travel.) ½-ton military trucks must be able to go up a 60% grade in low gear with a 1000-lb load; up a 7% grade in high gear with the same load; and up a 5% grade in high gear with the same load plus a towing load of another 1000 lb. 1½-ton military trucks must be able to go up a 60% grade in low gear with a 3000-lb load; a 5% grade in high gear with a 3000-lb load and a 4000-lb towed load. A 4-ton six-wheel truck must transport a 4-ton payload and tow 11,000 lb at 40 mph in high gear and at 2½ mph in low; it must climb a 3% grade in high gear and a 65% incline in low. All types must have all-wheel drives, and fuel, cooling, and lubrication systems that will operate on very steep slopes.

The following discussion will review in general the more important limitations that render passenger cars and light commercial

trucks unsuitable for military service without certain changes, together with the modifications that are made to give them the power and ruggedness essential for the service required in modern warfare.

It should be emphasized here that modern passenger cars and commercial trucks are in no way deficient in performance *under the operating conditions for which they are designed.* It should be remembered also that not *all* passenger cars and commercial trucks are deficient for military service in *all* the phases to be discussed, and hence may not need all the modifications described.

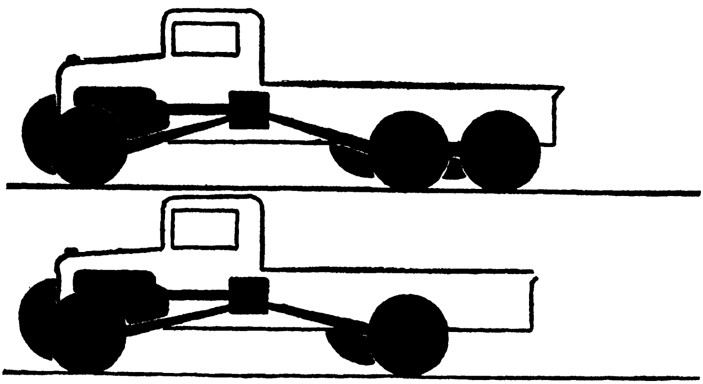


Fig. 196 — Schematic diagram of two types of military truck drives — (above) six-wheel all-wheel drive — (below) four-wheel all-wheel drive

Traction and Grade Ability. — The two-rear-wheel drive furnished in passenger cars and light commercial trucks does not furnish sufficient traction to negotiate the steep hills, ditches, streams, trenches, and rough, muddy, or sandy terrain encountered in military service since ability to obtain traction depends largely upon the load imposed upon the rear driving wheels.

Traction is dependent upon the friction between the ground and the tires of the driving wheels. The friction between the tires and the ground, in turn, is dependent upon the weight on the driving wheels. With two-wheel-drive vehicles the weight on the driving wheels is seldom more than 60 to 75% of the gross weight of the vehicle, even when fully loaded; frequently it is a smaller percentage. With four-wheel drive on four-wheel vehicles and six-wheel drive on six-wheel trucks the full weight of the vehicle is carried on the driving wheels, thus permitting maximum traction. Since the front driving wheels tend to pull the vehicle along as the rear driving wheels push it, they help in pulling themselves up out of ruts and over obstacles which the idling front wheels of a two-

wheel-drive vehicle would have difficulty in passing. Conditions often arise in which one set of wheels of a four- or six-wheel drive vehicle is driven through a slippery place by the other set or sets of wheels which are on ground affording adequate traction.

The replacement of two-wheel drive with four-wheel drive on four-wheel vehicles, and of two- or four-wheel drive with six-wheel

Fig. 197 — Front view of ½-ton military truck showing arrangement of front-axle drive

drive on six-wheel vehicles, is the major modification that must be made to adapt commercial trucks and passenger cars to military service, and is the change that has the greatest effect on fundamental design and production.

Four-Wheel Drive. — The flow of power from the engine to all four wheels of a four-wheel-drive vehicle is illustrated schematically at the bottom of Fig. 196. This type of drive is used on all ¼-, ½-, and 1½-ton military trucks. The engine is usually mounted higher than it is in passenger cars and many light commercial trucks to protect it from water when fording streams, and from mud and obstacles. From the engine, clutch, and transmission assembly, a

short propeller shaft transmits the power horizontally to a transfer gear box shown in the center of the vehicle. From the lower part of the transfer box one propeller shaft extends backward to the rear-axle gears in the conventional manner, and a second propeller shaft projects from the right side of the transfer box forward to the front-axle gears (Fig. 197). The front axle, front-axle gears, and front-axle differential are of similar or the same construction as the

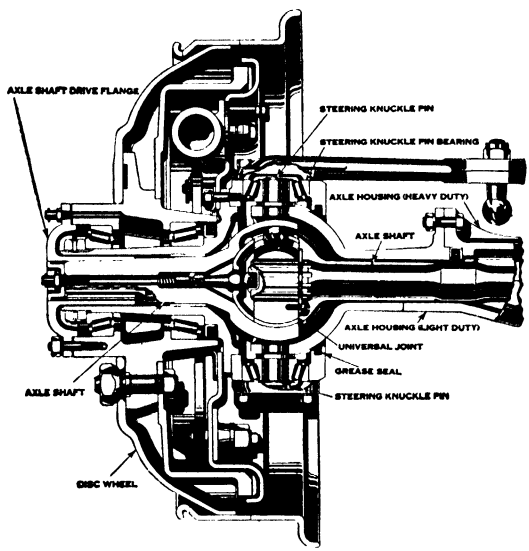


Fig. 198—Section of military front-drive axle showing arrangement of universal joint and steering linkage to produce front drive in a steering axle

rear axle, rear-axle gears and rear-axle differential with one important difference necessary to permit steering. To allow the front wheels to be turned for steering at the same time that they are being driven by the engine, special types of constant-velocity universal joints are used to replace steering knuckles of conventional vehicles (Fig. 198). Because of the high torque in the axle shafts and the large angular steering movement, these universal joints must be of special design. The front driving axle utilizes most of the parts used in the commercial-type rear driving axle to provide maximum interchangeability.

From this discussion it is evident that the necessary modification to replace two-wheel drive with four-wheel drive is to interpose a transfer case in the conventional propeller shaft and add front-wheel drive. Since the all-wheel drives of military trucks are of the

Hotchkiss type, both front-axle and rear-axle propeller shafts are provided with a roller or needle-bearing type universal joint at each end. Rear-axle and front-axle gears are either of the hypoid or spiral-bevel type. Provision for declutching or disengaging the front-wheel drive when its use is not necessary (for example, when traveling on paved highways) is usually incorporated in the transfer case of the drive.

In one make of 1½-ton military truck, the two-speed transfer case has gear ratios of 1:1 and 1.94:1; gears are made of heat-treated alloy steel. This design of military truck drive incorporates hypoid drive gears in the front and rear axles which are of full-floating design — the same design used on commercial trucks of the same make. To retain essentially the same design of front axle as the rear axle, the former unit is rotated 180 deg with the pinion in the rear position and above the ring-gear center. The ring gear turns in the same forward direction as does the rear-axle unit to maintain the maximum efficiency of the hypoid design. This is accomplished by incorporating an additional shaft and gear set in the transfer unit so that the front-drive propeller shaft is rotated opposite to the rear-axle propeller shaft. These trucks are provided with a rolling-ball type of universal joint at the front wheels to permit steering. This universal joint is designed so that it transmits a constant angular velocity.

Another large producer of military trucks uses hypoid gears on ½-ton military trucks and spiral gears on 1½-ton models. The axle ratio for ½-ton trucks is 4.89:1, and for 1½-ton trucks is 6.6:1. Front wheel stops are employed to limit the angle of cramping to 28 deg. Both front and rear differential assemblies are interchangeable for each size of truck. Constant-velocity universal joints are used in the front-axle steering drive ends. Both front and rear axles are of the full-floating type.

Six-Wheel Drive. — This type of drive is used on all 2½-, 4-, and 6-ton military trucks. This drive is shown schematically in the upper part of Fig. 196. Power flows from the engine to the transfer case through an engine propeller shaft, and from the front of the transfer case forward to the front axle through a front propeller shaft, the same as it does in the four-wheel drive. From this point, each of the rear axles is driven by a separate propeller shaft extending from the transfer case, comprising a tandem-drive rear-axle unit. (See Fig. 199.)

Tires. — Tires used on passenger cars and conventional light trucks are ill-suited for use on military trucks because they are

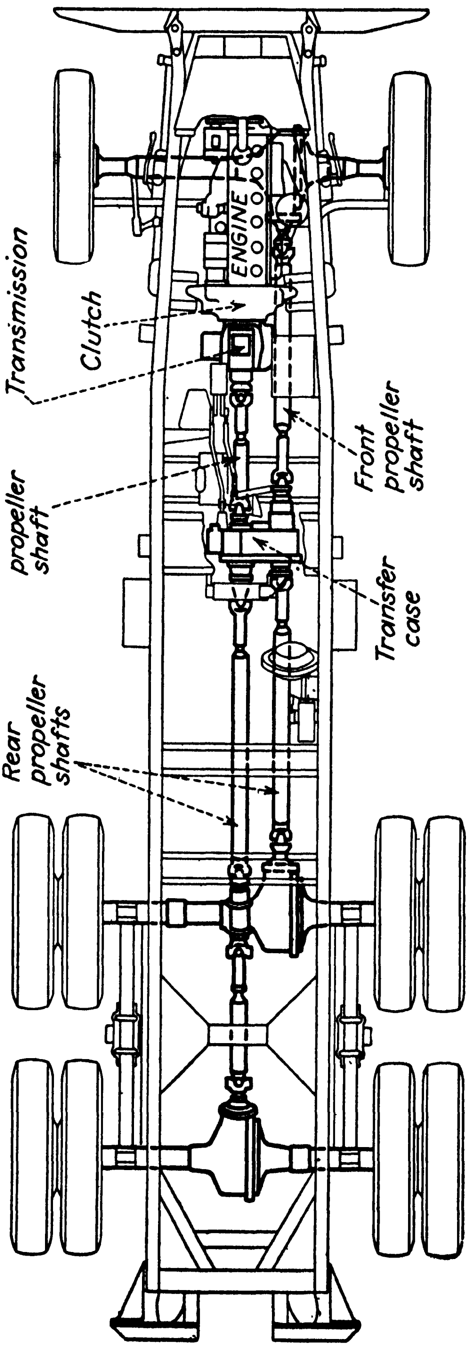


Fig. 199 — Plan view of chassis of six-wheel all-wheel drive military truck showing arrangement of front driving axle, transfer case, and tandem-drive rear-axle unit

deficient in size and ruggedness, and their tread does not give sufficient traction. For military service, therefore, these tires usually are replaced by extra-large heavy-duty tires with extra-heavy tread design to provide maximum traction in mud and snow. (See Fig. 194.) In fact, tires for military trucks are often of such heavy construction that they will not collapse after a blowout and, consequently, are able to support the weight of the truck for a considerable distance without air pressure.

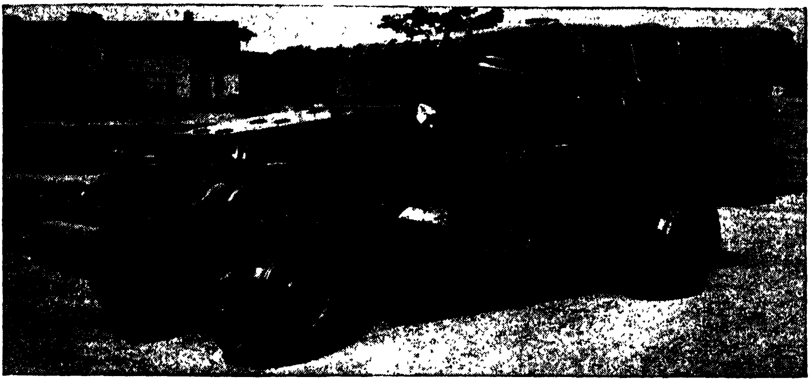


Fig. 200 — Military scout car. These units have four-wheel drive and are designed for reconnaissance work ahead of the fighting forces. They are fully covered with armor plate for protection against rifle or machine-gun bullets; are equipped with steel plates which can be dropped down over the bullet-proof windshield; and have tires with bullet-sealing tubes. The roller shown on the front end helps to lift the car out of ditches. Inside, a two-way radio is provided for communication with headquarters

Furthermore, tires of military trucks used for combat (Fig. 200) are frequently equipped with special bullet-sealing tubes. To provide additional traction in cases of emergency, military trucks usually carry chains or other traction devices for installation under such conditions. In addition, the front-end construction of virtually all military trucks is adapted to permit the installation of dual wheel equipment, allowing still more traction.

The ratio of the tire area in contact with the ground to the gross vehicle weight is called "flotation." For maximum traction and grade ability, the flotation of military trucks should be as large as practicable; consequently, tires for military trucks are designed to attain this objective.

Engines. — Although ample for normal roads and reasonable grades, the power and torque delivered by the engines furnished with conventional passenger cars and trucks are sometimes inadequate

for military service, especially at low speeds. The oiling, cooling, and carburetion systems of such engines seldom operate efficiently (if at all) upon grades steeper than 30 deg. Any attempt to use such engines for descending steep slopes is likely to result in considerable loss of cooling fluid due to overflow of the radiator which may seriously affect the operation of the engine unless the lost fluid is replaced immediately. Often, too, the capacity of conventional cooling systems is inadequate for military service; to attempt to use such systems would probably necessitate frequent halts to permit the vehicles to cool. On steep upgrades the fuel supply may be cut off because of the design of the carburetor, or the level of the oil in the crankcase may be changed so as to impede or prohibit proper lubrication of the bearings and other moving parts. Most such engines also are inadequately protected against the extremely dusty air encountered in military service.

In general, these limitations are eliminated by providing more powerful high-torque engines; by the installation of heavy-duty cooling fans, larger-capacity radiator cores, and bypasses to prevent loss of cooling fluid; by specially designed and deeper oil sumps; by modifications in the carburetor and fuel system to permit them to operate at virtually any angle; and by the provision of heavy-duty types of air cleaners, fuel filters, and oil filters.

In the case of one make of 1½-ton military truck, for example, a special 6-cyl I-head high-torque engine is employed in the military truck; it is of the same basic design as the engine regularly used in commercial 1½-ton trucks of the same make, but its bore and stroke are 1/16 in. larger giving a piston displacement of 235.5 cu in. It produces a torque of 192 ft-lb as compared with 174 ft-lb for the regular commercial engine, and this torque is available over a wide range from 1 mph in low gear to 30 mph in high gear, thus providing maximum pulling ability at speeds where it is needed most. The compression ratio of the high-torque military truck engine is 6.62:1 as compared with 6.50:1 for the regular commercial engine. To maintain an adequate supply of oil at the oil pump when the truck is negotiating excessive grades, the sump in the oil pan has been made deeper than in the regular commercial design. This engine also is provided with a steam bypass from the rear of the cylinder head to the radiator to aid in cooling, an oil-bath air cleaner, auxiliary fuel filter, and oil filter. A governor restricts the top speed to 45 mph.

The engine supplied in the 1½-ton military trucks furnished by another manufacturer is of the 6-cyl L-head type, bore and stroke

3⅜ in. by 4½ in., 241.5 cu in. displacement, developing 188 ft-lb torque at 1200 rpm and 99 hp at 3000 rpm. To facilitate operation of the engine lubrication and fuel systems when these trucks are operated on excessively steep grades and slopes, the shape of the crankcase ventilator outlet pipe has been modified and a tapered wedge has been provided between the carburetor and the intake manifold flanges. A governor of the velocity type restricts the speed of the engines to 3100 rpm, equivalent to 47 mph truck speed in high gear.

One make of 4-ton truck employs a 501 cu in. engine.

Transmissions and Axle Gear Ratios. — In addition to the provision of all-wheel drives, heavy-duty tires, and more powerful engines, the traction and grade ability (hill-climbing ability) of military trucks are increased further by raising the gear ratio in low speed and by multiplying the number of gear ratios available in the power-transmission system.

By providing higher gear ratios for low speeds, the torque available at the driving wheels is multiplied and, hence, the traction and grade ability of the vehicles are increased because of additional mechanical advantage, as explained in Chapter III. The overall low gear ratio of 1½-ton commercial trucks provided with a four-speed transmission and two-wheel drive is usually between 36 and 48:1 (ratio of engine crankshaft speed to speed of driving wheels when in low gear). Passenger cars and ½-ton commercial trucks from which ½-ton military trucks are adapted usually employ three-speed transmissions, two-wheel drive and an overall gear ratio in low speed of about 12 or 13:1.

To adapt such vehicles for military service, however, this overall ratio in low gear is increased considerably; usually it is approximately doubled. An auxiliary two-speed geared transmission included in the transfer box usually accounts for most of the increase in low gear ratio possible in military trucks. An extra lever is provided alongside the gearshift lever in the driver's compartment for shifting gears in the auxiliary transfer unit. The two ratios provided in this unit are direct drive (1:1 ratio) and slightly under 2:1. Thus, the number of speeds formerly available through the conventional transmission is doubled. For example, a 1½-ton commercial truck with four-speed transmission, when modified for military service by the addition of an auxiliary two-speed transmission in the transfer box, will have eight speeds forward instead of four (two speed ranges for the four speeds of the conventional transmission). In addition, front-axle and rear-axle gear ratios are

often about 20% higher in military units than those of the conventional vehicles from which they are adapted. A power take-off is frequently provided on one side of the four- or five-speed transmission used in military trucks to drive a winch or dump body hoist. Four-speed transmissions usually are provided in the lighter military trucks, and five-speed transmissions in the heavier units.

The four-speed transmission of one make of 1½-ton military truck has the following ratios: 1st, 6.4:1; 2nd, 3.09:1; 3rd, 1.69:1; 4th, direct; and reverse, 7.82:1.

Axle Overhang. — The frame and body of the average passenger car and commercial truck usually extend too far beyond the rear axle to meet the requirements of military service. Sometimes, also, the overhang at the front axle is too great. In order that military trucks may cross ditches, climb and descend steep slopes, and traverse uneven terrain without interference, the length of these extensions frequently must be reduced. Short rear overhang is especially essential for military vehicles that are used as tow trucks, in order to avoid imbedding the towing connection in the ground when negotiating steep slopes. In most cases this modification necessitates only minor changes, such as reducing the frame length by cutting off the extended rear ends of the frame side rails.

To assist certain types of military combat vehicles, rollers are provided on the front end to help lift them out of ditches. Such a roller is shown clearly in the scout car shown in Fig. 200.

Springs. — Being designed for roads and for comfort, springs for passenger vehicles and light commercial trucks are usually too "soft" and flexible (that is, their "rate" is too low) for the ardors of military service. Frequently this condition necessitates that the springs be replaced by heavier, stiffer semi-elliptic units. In some cases the necessary strength and stiffness can be provided by adding leaves. The conventional independent front-wheel suspension employing coil springs used in passenger cars is replaced by longitudinal leaf springs when these units are converted to military service. There are two reasons for this change: (1) the coil springs are too flexible and (2) independent front-wheel suspension is not adapted to the Hotchkiss type of front-wheel drive used in military trucks. Double-acting hydraulic shock absorbers are generally used in conjunction with the leaf springs used in these trucks.

Axle-Clearance. — Military trucks must have a greater clearance between the ground and axles than have any passenger vehicles and most commercial trucks. Unless this clearance is adequate, the military vehicles are likely to be damaged and stalled by the stumps,

stones, high road centers, deep wheel ruts, and so on, encountered in cross-country travel. Usually the clearance is increased sufficiently by the use of tires of larger diameter than those employed in the conventional vehicles. If this change does not raise the axle clearance sufficiently, modifications in springs, frames, or other chassis parts must be made to give the required result.

Frames. — Heavier frames (see Fig. 199) frequently must be provided for military vehicles than for passenger and commercial types to withstand the severe twisting to which they are subjected in this severe service. Consequently the frame side rails are often made deeper and, in some cases, special alloy steels are used. The 8-in. frame side rail of one 1½-ton military design has 10% more sectional strength than has the side rail of the frame for 1½-ton conventional trucks of the same make. These frames usually are narrower than commercial types to provide clearance for chains and other traction devices. Also, they usually are mounted higher to maintain adequate clearances over the front axle and under the transfer box. To provide a strong mounting for the tow hooks usually located at the front end of each side rail, and the pintle attached to the rear of the frame, the heavier frames are reinforced at these locations. This reinforcement at the front of the frame also is designed to withstand winch operation. Often commercial designs of frame must be modified to reduce the axle overhang and to provide adequate axle clearance, as explained previously. Extra-heavy bumpers, usually steel channels, are generally attached to the front and rear of these frames.

Fuel Tanks. — In general, the metal thickness of the fuel tanks for military trucks is greater than that for fuel tanks on commercial vehicles. In some cases for combat vehicles, the tanks are of the bullet-sealing type used for military aircraft. On one design of 1½-ton truck a 30-gal fuel tank is supported by brackets extending down from the right side rail so that the tank is located just ahead of the rear axle and inside the rail.

Brakes. — Light military trucks employ hydraulic brakes similar to those used in passenger cars and light commercial vehicles, whereas heavy six-wheel military trucks are provided with air brakes on all six wheels and emergency four-shoe parking brakes.

An external-contracting emergency brake is assembled to the transmission of the ½-ton military trucks, and to the transfer case of the 1½-ton military trucks produced by one maker. On another make of 1½-ton truck, the handbrake is attached to the rear wheels in the same manner as in passenger cars.

Steering. — To offset the greater steering forces encountered with a front drive over the conventional axle arrangement, one design of 1½-ton military truck is provided with a recirculating-ball type steering gear with a steering ratio of 23.6:1 in combination with a 20-in. diameter steering wheel. Other designs use similar means. The steering problem becomes more acute with traction devices or chains on the front tires, particularly with dual wheels on the front axles.

Sheet Metal and Cabs. — Sheet metal on military trucks is simplified for utility, but its construction and mounting is made unusually rigid to take the extreme twisting to which these trucks will be subjected.

Sheet metal is designed as low as possible to give maximum road vision ahead, the hoods of some designs sloping downward. Front fenders are of the mud-guard type to provide adequate clearances for dual wheel equipment with traction devices. For easy access to the engine compartment, one design employs an alligator jaw hood used in combination with side panels that can be removed or mounted quickly.

The conventional radiator grille is usually replaced by a brush guard that protects both the radiator core and the headlamps. Small blackout lamps are provided on the front fenders and at the rear for emergencies. One blackout lighting system consists of two headlamps; two blackout front parking lamps; one left-rear combination tail, stop, and blackout lamp, and one right-rear blackout lamp. The tail lamps also are shielded.

The three-man military truck cab of one design has a special three-point spring mounting for flexibility, which is necessary to counteract the excessive twisting that results when traveling over rough ground. A blackout light switch on the instrument panel of this same model is designed to prevent turning on the headlamps when the blackout lamps are in use.

A special windshield is provided on some body types of military trucks which is hinged at the bottom and permits the windshield to be folded forward over the hinges. Some designs also include hinges at the top of the stanchions to allow opening at the bottom.

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SOURCES OF VISUAL AIDS

The organizations listed below provide visual aids in the form of moving pictures and slide films. Inasmuch as offerings of these organizations vary from time to time, it was thought undesirable to list the moving pictures or slide films individually. It is suggested that the organizations be contacted for current information concerning the various types of visual aids:

U. S. Reamer & Tool Company	Los Angeles, Cal.
Bijur Automotive Company	Bridgeport, Conn.
The Whitney Mfg. Company	Hartford, Conn.
Fafnir Bearing Company	New Britain, Conn.
Standard Bearing Company	Plainville, Conn.
United States Department of Agriculture, Extension Service	Washington, D. C.
Cedar Rapids Eng. Company	Cedar Rapids, Iowa
Sioux Tool Company	Sioux City, Iowa
Alemite Company	Chicago, Ill.
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Borg & Beck Division, Borg-Warner Corp.	Chicago, Ill.
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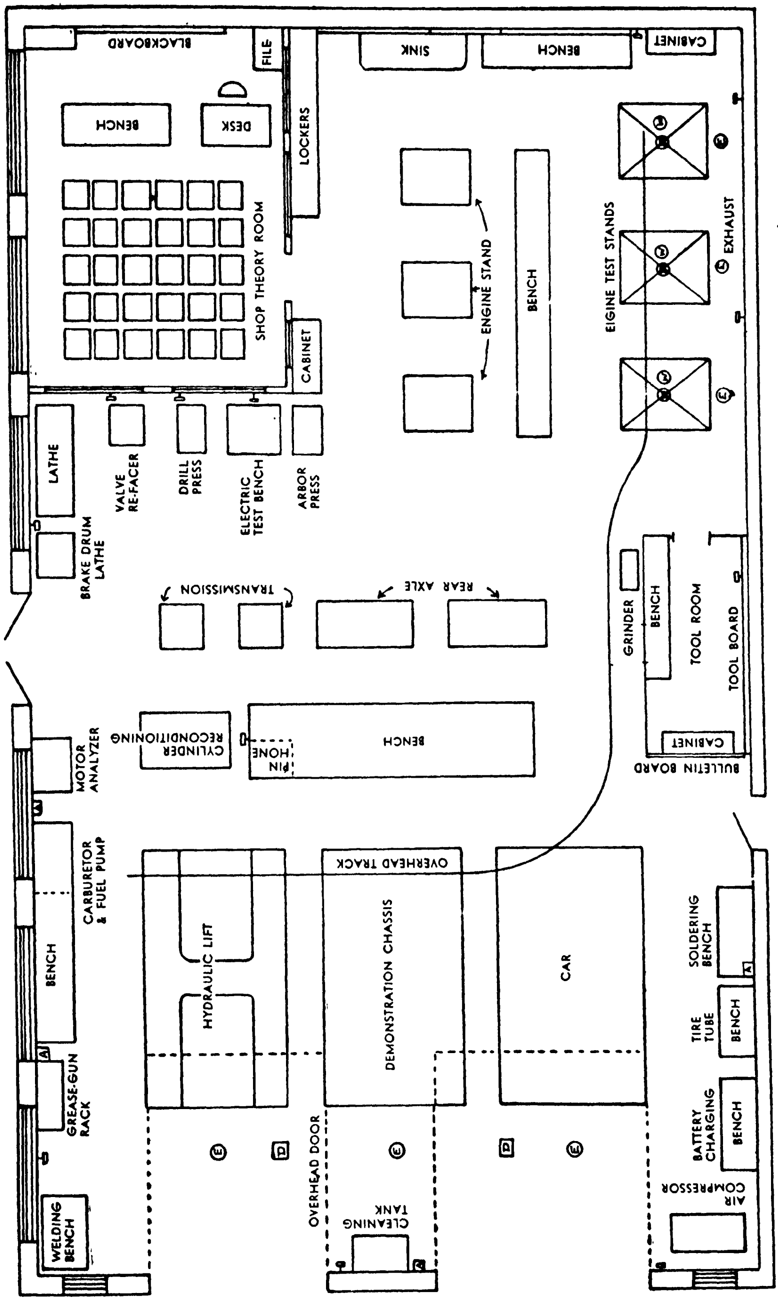
Long Mfg. Division, Borg-Warner Corp.	Detroit, Mich.
McCord Radiator & Mfg. Company	Detroit, Mich.
Plymouth Division, Chrysler Corp.	Detroit, Mich.
Timken-Detroit Axle Company	Detroit, Mich.
AC Spark Division, General Motors Corp.	Flint, Mich.
Chevrolet Motor Division, General Motors Corp.	Detroit, Mich.
Fuller Mfg. Company	Kalamazoo, Mich.
Monroe Auto Equip. Company	Monroe, Mich.
Spicer Mfg. Company	Toledo, Ohio
Trico Products Corporation	Buffalo, N. Y.
Air Reduction Sales Company	New York City
F. H. Leggett Co.	New York City
United States Rubber Company	New York City
Carborundum Company	Niagara Falls, N. Y.
North East Electric Company	Rochester, N. Y.
General Electric Company	Schenectady, N. Y.
Firestone Tire & Rubber Company	Akron, Ohio
Goodyear Tire & Rubber Company	Akron, Ohio
Timken Roller Bearing Company	Canton, Ohio
Cleveland Twist Drill Company	Cleveland, Ohio
The Glidden Paint Company	Cleveland, Ohio
Guide Lamp Division, General Motors Corp.	Cleveland, Ohio
Willard Storage Battery Company	Cleveland, Ohio
American Rolling Mill Company	Middletown, Ohio
Champion Spark Plug Company	Toledo, Ohio
Electric Auto-Lite Company	Toledo, Ohio
Tillotson Mfg. Company	Toledo, Ohio

The Magee Carpet Company	Bloomsburg, Pa.
The Budd Wheel Company	Philadelphia, Pa.
United States Bureau of Mines	Pittsburgh, Pa.
Willis Jones Mach. Company	Seattle, Wash.
Wausau Motor Parts Company	Wausau, Wis.

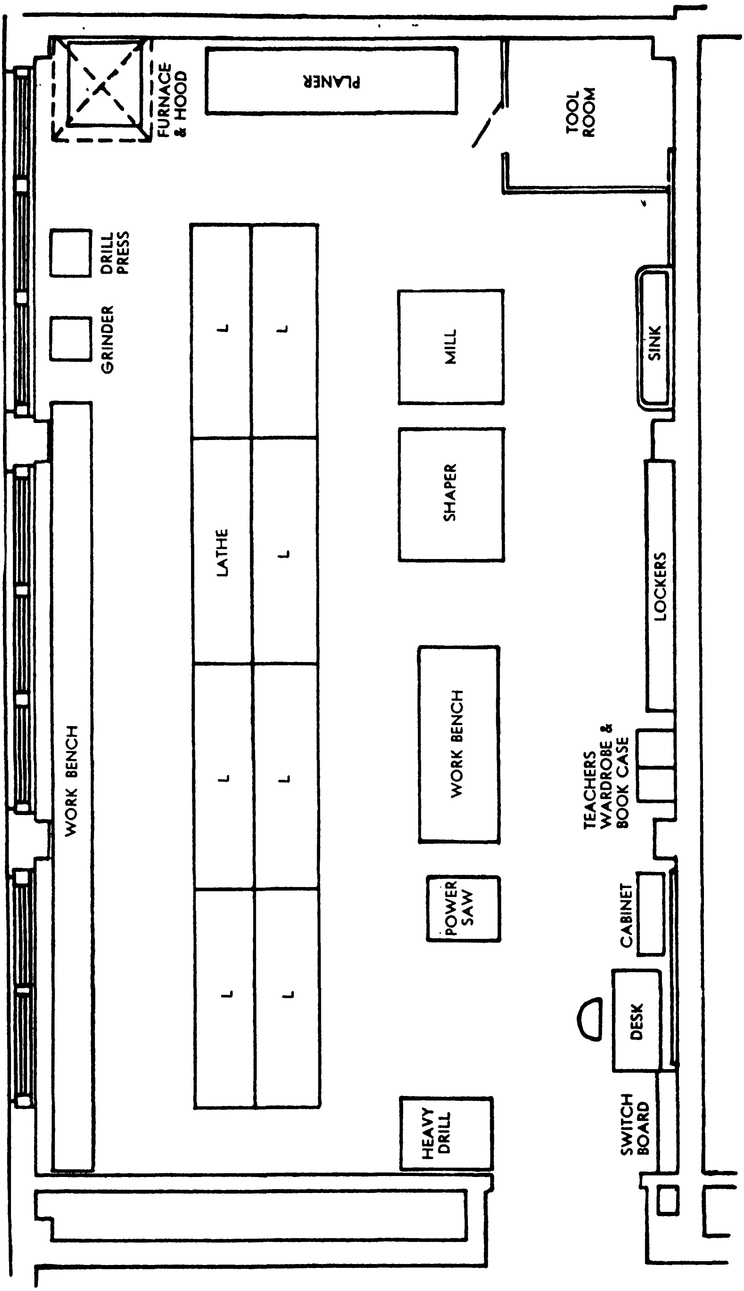
AUTOMOBILE SHOP FLOOR PLANS

The floor plans included in this section were developed to be used in a four-year course in Automobile Mechanics for Vocational High Schools. The shops are now in use in the Burgard Vocational High School, Buffalo, New York. The layouts should be of interest to both instructors and students.

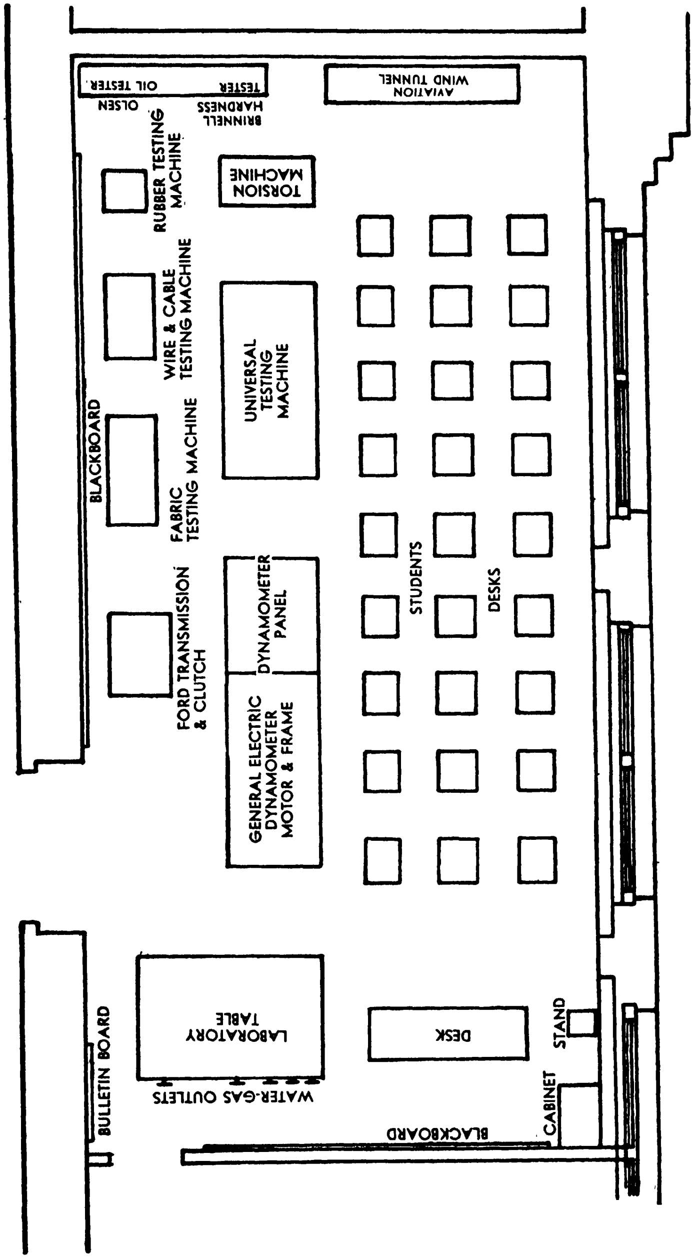
Each plan shows the shop dimensions as well as the type of equipment and its suggested location. The number of cars that can be accommodated in each shop is also indicated. This material is reproduced through the courtesy of the New York State Department of Education.



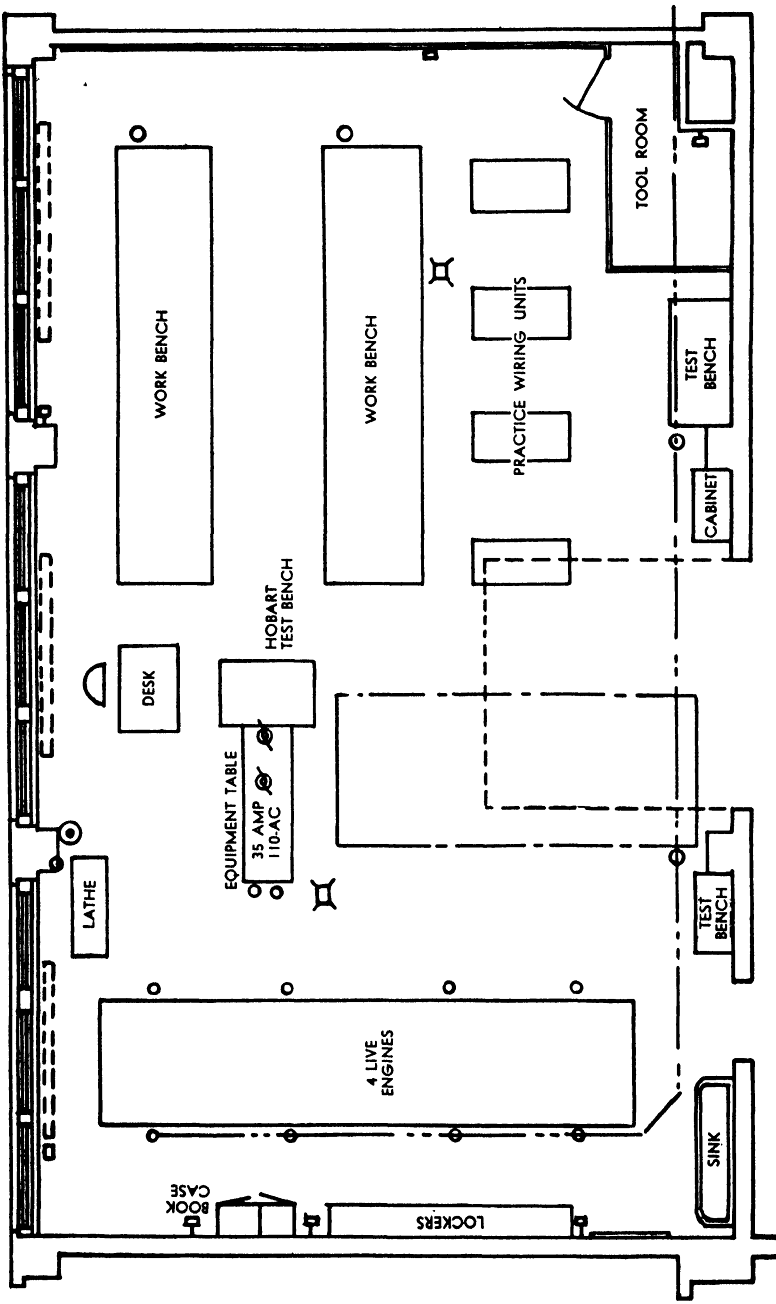
Plan 1. General shop — automobile mechanics. Dimensions 68′ × 42′. Two car capacity.



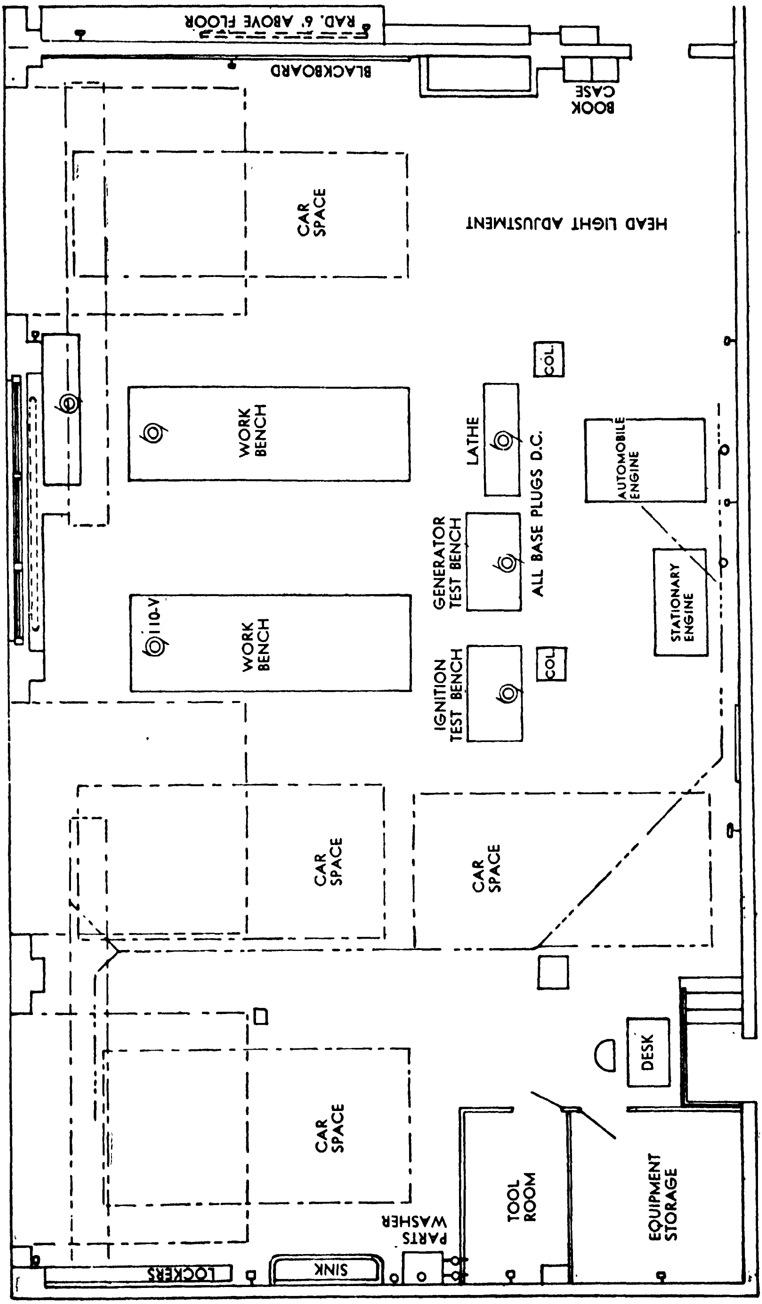
Plan 2. Automobile machine shop. Dimensions 45′ × 26′. No car space.



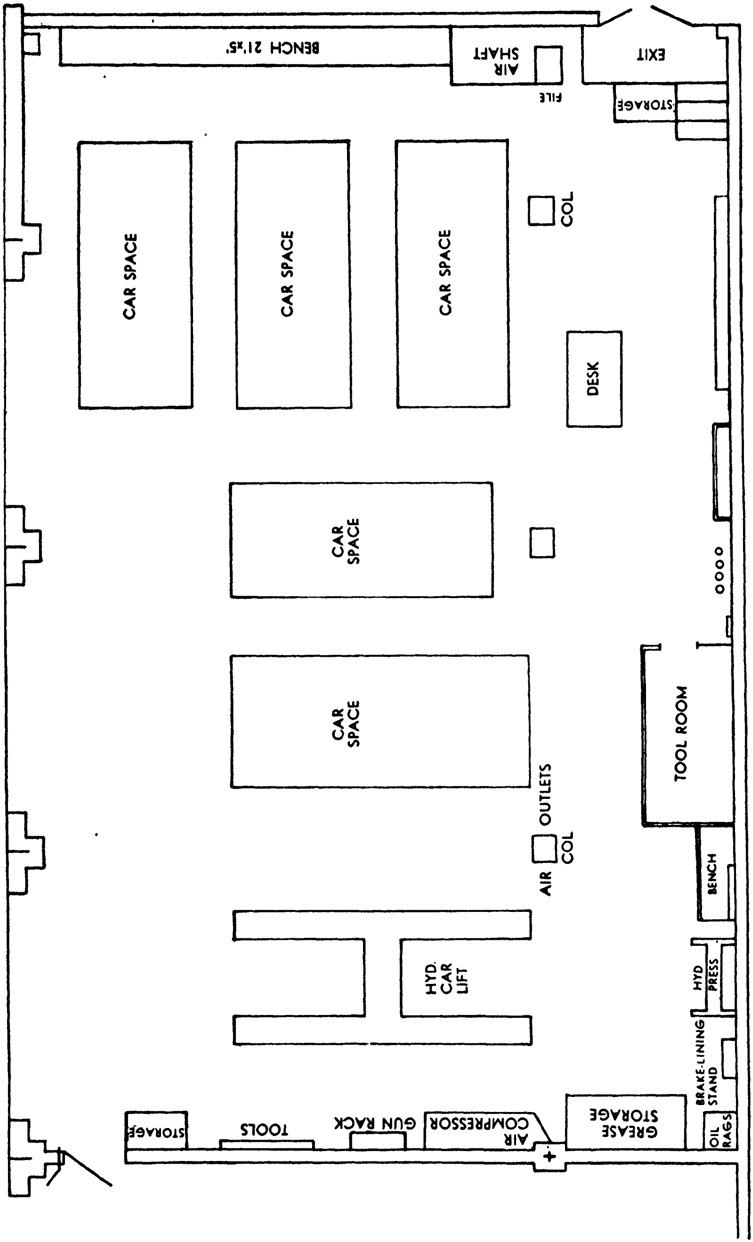
Plan 3. Automobile related trade science laboratory. Dimensions 47′ × 28′.



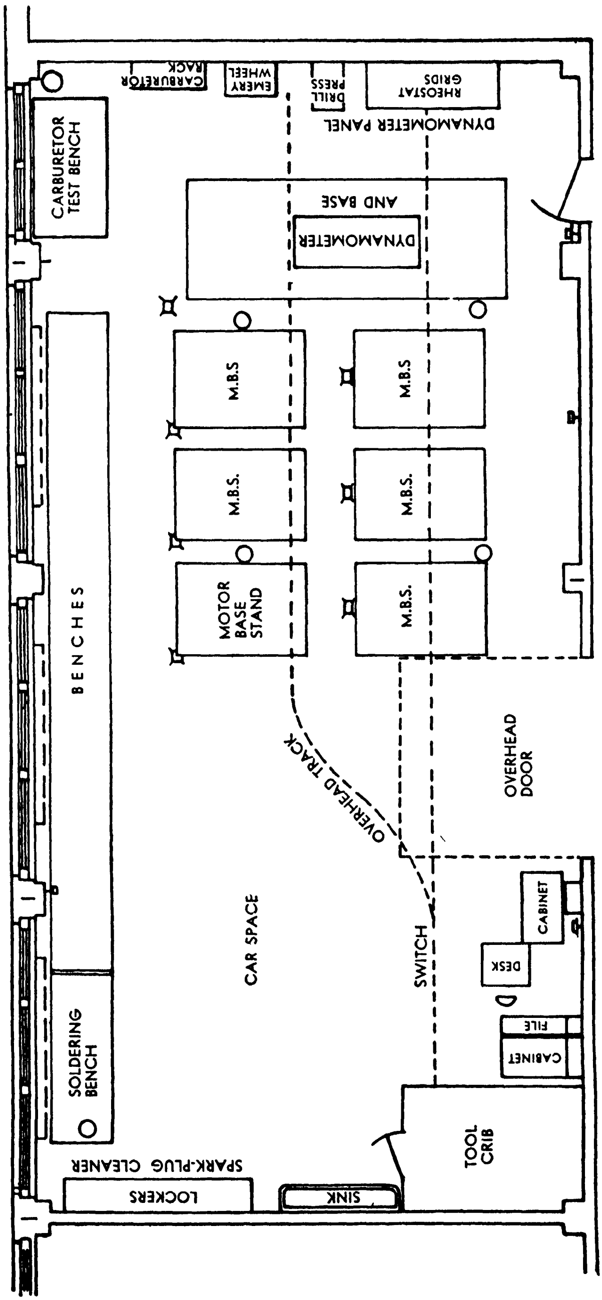
Plan 4. Automobile ignition — starting and lighting. Dimensions 47′ × 28′. Two car capacity.



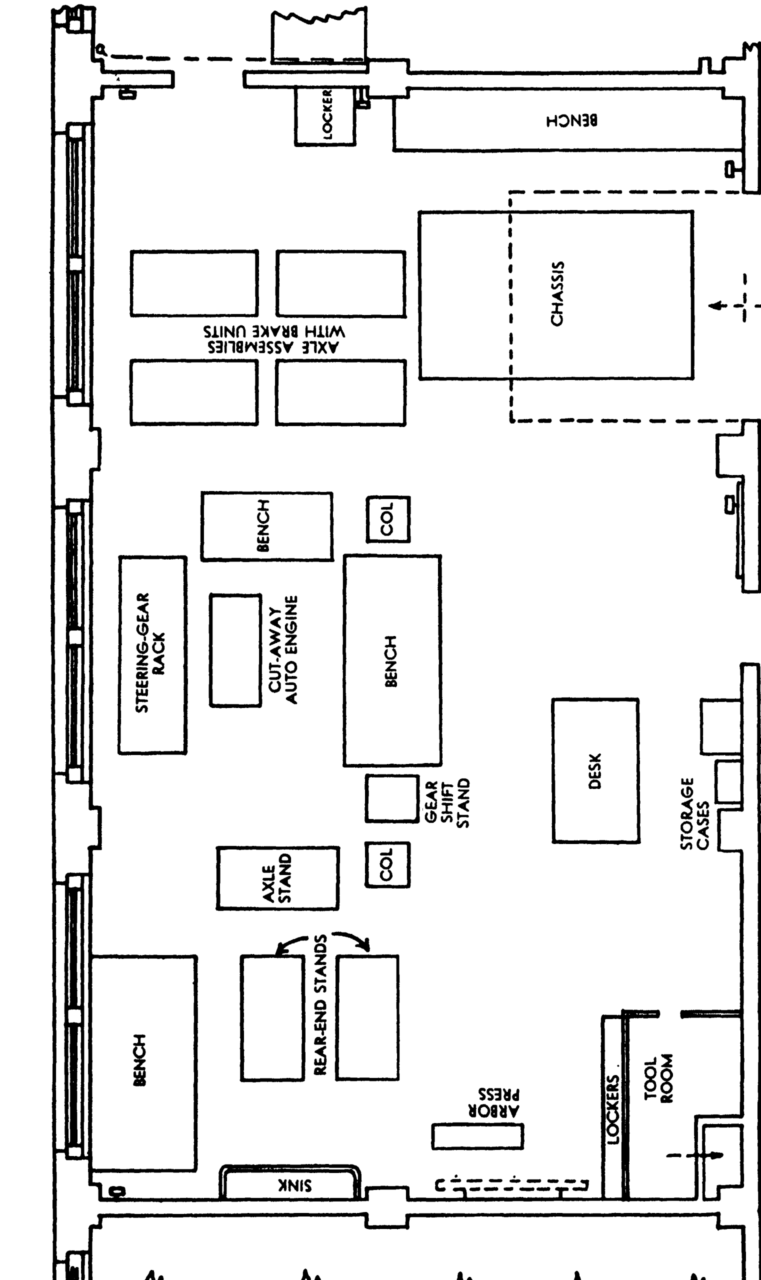
Plan 5. Automobile electrical repair (advanced). Dimensions 64′ × 32′. Seven car capacity.



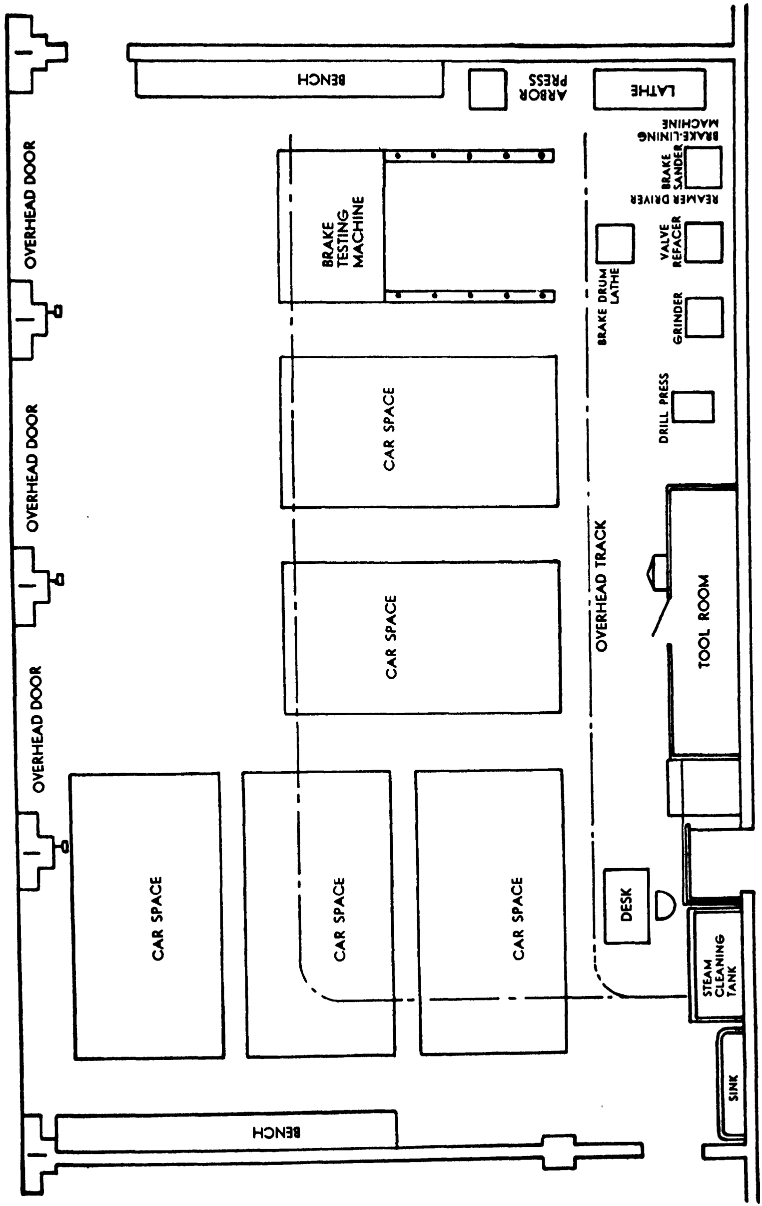
Plan 6. Automobile lubrication and mechanical repair. Dimensions 58′ × 38′. Seven car capacity.



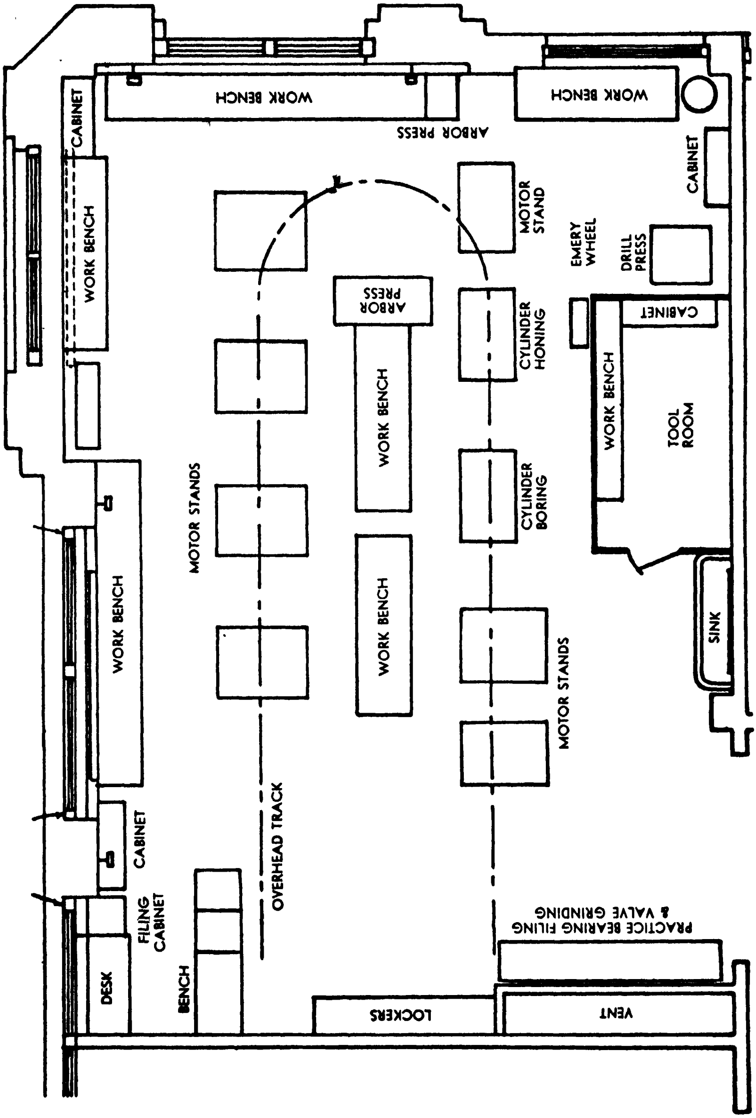
Plan 7. Automobile carburetor repair, engine trouble shooting, and dynamometer test. Dimensions 58′ × 28′. Two car capacity.



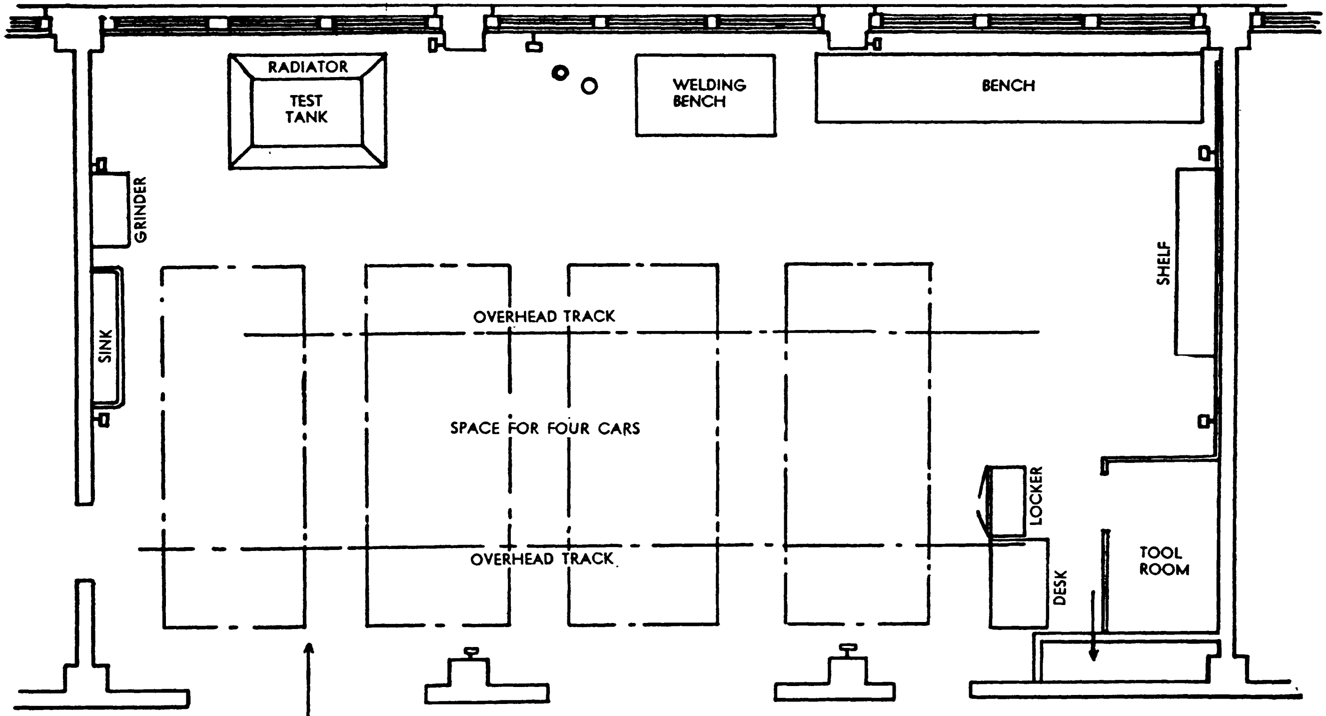
Plan 8. Automobile chassis repair. Dimensions 48′ × 29′. Two car capacity.



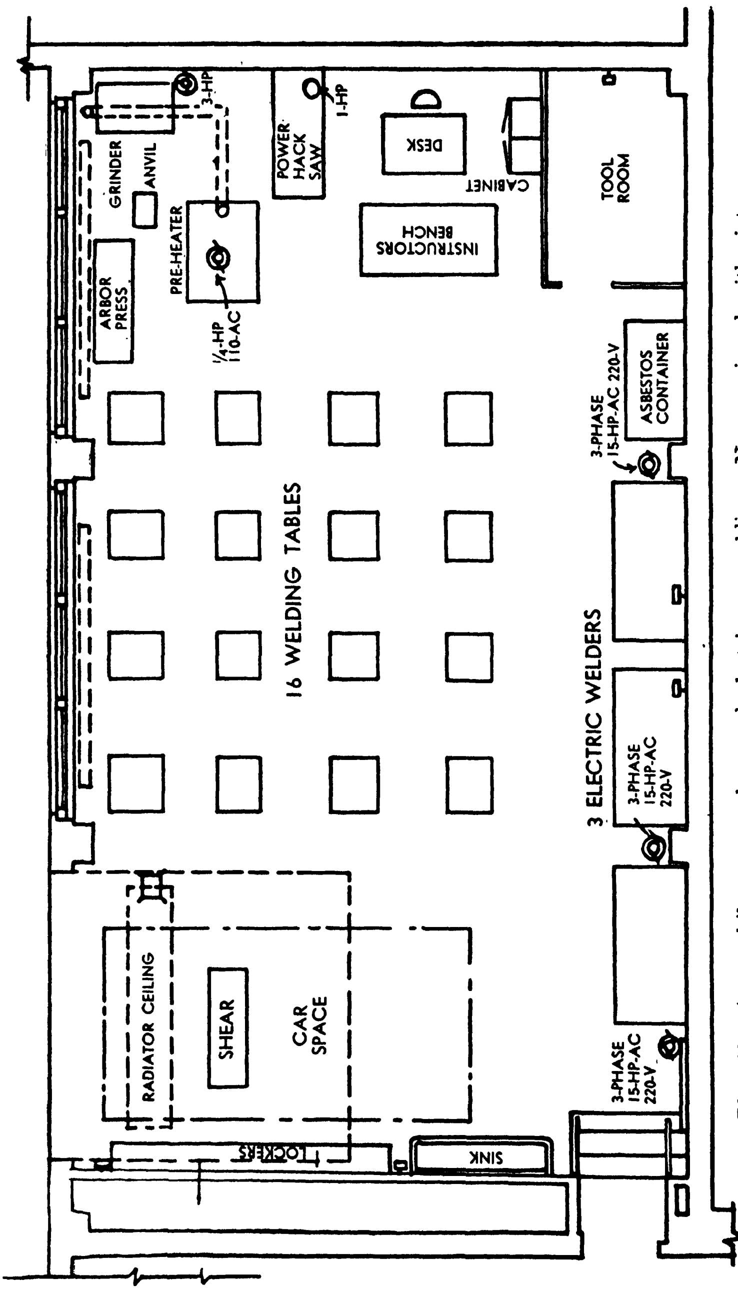
Plan 9. Automobile mechanical repair (advanced). Dimensions 47′ × 38′. Six car capacity.



Plan 10. Automobile engine repair. Dimensions 48′ × 28′. One car capacity.



Plan 11. Automobile collision and radiator work (preparation). Dimensions 47′ × 28′. Adjoining shop of same size for painting and spraying. The two shops can accommodate nine cars at one time.



Plan 12. Automobile oxyacetylene and electric arc welding. Now equipped with sixteen electric welders and six oxyacetylene units. Dimensions 45′ × 27½′. No car space.

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